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Proposal for Auger Project Detector R&D

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1 Introduction

We request funding for the University component of a comprehensive Auger Project R&D program in 1996 and 1997. The primary goal of the R&D is to develop custom components and refine our detector designs through field testing to the point that they will be ready for mass production.

We will first describe the intended R&D program. For completeness we will include expected contributions from Fermilab and foreign collaborators. We will then identify those items for which we are requesting R&D funding from the DoE in this proposal.

2 Scientific Motivation

This proposal describes a program of research and development of detectors for the *Auger Project*, an experiment planned to study the highest energy cosmic rays. A full description of the project is beyond the scope of this proposal. A detailed presentation, including the specifics of the hardware required, will appear in the Final Report of the Giant Airshower Detectors Design Group. That document summarizes the work of a six-month workshop conducted at Fermilab in 1995.

In this section we briefly review the goals of the Auger Project and the requirements that the science places on the detectors.

2.1 The Auger Project: Science

The nature and origin of the most energetic cosmic rays are profound mysteries. The non-thermal energy spectrum, unusual in astrophysics, suggests interesting physical processes at the source. The magnitude of cosmic-ray energy is also striking: particles have been observed with energies beyond 10^{20} eV [1][2]. Accelerators capable of such enormous energy must be quite remarkable. A successful theory must predict both the extraordinary energies and the character of the spectrum.

Hillas[3] and others[4] have presented dimensional arguments pointing out that there are only a few types of objects in the cosmos with sufficient size and magnetic field strength to achieve these energies through conventional mechanisms such as Fermi acceleration. Since a source must also be configured to allow the particles to escape and reach the earth, the possibilities are constrained even further.

Our own Galaxy cannot contain 10^{20} eV particles because of their large Larmor radius in a 10^{-6} G magnetic field. The few observed events do not come from the direction of any interesting local objects. Thus our Galaxy is an unlikely source of these cosmic rays. One promising model[5] postulates that the "hot-spots" observed in radio images of jets from certain Active Galactic Nuclei may signify the location of sources of 10^{20}eV protons. More speculative theories include those which invoke the decay of relics of the early universe ("topological defects")[6].

A severe constraint on the location of cosmic ray accelerators is that the Universe becomes opaque to subatomic particles at extreme energies. Nucleons and nuclei interact with the ubiquitous cosmic microwave background radiation (CMBR). The energies of the resulting particles are degraded. The thresholds for interactions are similar for nucleons or nuclei, as are their respective interaction lengths at 10^{20} eV. Convoluting a spectrum of cosmic ray energies with the interaction on the CMBR predicts a strong modification of the spectrum observed at earth starting at about 5×10^{19} eV. This is the so-called Greisen-Zatsepin-Kuzmin (GZK) cutoff. It applies to hadronic cosmic rays which originate further than about 30 Mpc from earth, a rather short distance on cosmic scales. The allowed volume for the sources includes the center of our local (Virgo) supercluster of galaxies, but no others.

It is therefore important to measure the energy spectrum of the most energetic cosmic rays with precision. Observation of the GZK cutoff yields information on the distance and distribution of sources. Observation of significant numbers of events beyond the GZK cutoff implies that at least some sources are either nearby or that the CMBR is not uniform. Since there are few known candidate sources in the Earth's cosmic neighborhood, such a measurement would have important cosmological consequences.

If extremely energetic cosmic rays are not hadronic, other problems arise. Cosmic γ-rays also interact with universal background radiation producing e^+e^- pairs. Above 10^{20} eV, the targets are radio photons rather than microwave photons. The attenuation length should be less than 10 Mpc, so the universe is even more opaque to γ-rays than to protons. Neutrinos are the only known stable particles which are virtually unaffected by any background radiation fields. However, they are also virtually unaffected by the Earth's atmosphere, so they are not likely to be responsible for the highest energy air showers which have been observed.

So, as for protons or nuclei, a detectable flux of γ-rays or neutrinos from distant sources at extremely high energies is difficult to understand. The nature of the highest energy cosmic ray particles is therefore a mystery which the Auger Detector is designed to solve.

2.2 Auger Project: Design Considerations

To address the scientific questions described above, the specific goals of the Auger Project are to determine the following features of the highest energy cosmic rays: (1) the energy spectrum, (2) the arrival directions, and (3) the primary particle type(s). Certain design features and the overall scale of the project are mandatory, based on the experience of previous experiments.

The flux of the highest energy particles is extremely low. About 1000 events with energies in excess of 10^{19} eV have been identified in over 30 years of observation by several experiments. A handful of these are above 10^{20} eV. These data have proven insufficient to establish the existence (or absence) of the GZK cutoff. The design goal of the Auger Project is to collect 10^4 events per year above 10^{19} eV, which includes about 100 events per year above 10^{20} eV. The intensity of cosmic rays above 10^{19}eV has been measured to be 1 /km^2/year/sr, so the experiment must present a ground target area of about 5000 km^2, assuming it can record events from directions as far as 45° from the zenith.

The total number of particles striking the ground in extremely energetic air showers is approximately proportional to the energy of the primary particle. There must be enough ground stations registering hits to determine the shower size. Since the lateral extent of the air shower is a few kilometers, the spacing of the ground detector elements should not be greater than about 1.5 km, in order to accurately reconstruct shower parameters.

The direction of the shower is determined by analysis of the time-of-arrival of the shower front at several ground stations. The stations must therefore record the times of particle hits with respect to times of hits recorded by their neighbors. The thickness of the shower front is of the order of a few μsec. For 1 degree directional resolution, stations must record hits over this interval with relative accuracy better than 100 nsec, assuming 1.5 km spacing between stations. The stations will be equipped with GPS timing systems and communicate with each other over radio links.

A major difference between air showers initiated by protons and those from heavier nuclei involves the relative number of muons with respect to the more numerous electrons and photons in the shower. The detectors must be able to resolve particle types. The Auger project has elected to use water-Cherenkov tanks. Air shower muons, with average energies of about 1 GeV, will generate Cherenkov light pulses in water with different characteristics than those generated by the MeV electrons. The detector electronics are designed to record and distinguish large pulses of light from the more numerous smaller ones. The ground array planned for the Auger Project will build upon the experience of the Haverah Park experiment which studied the highest energy cosmic rays for 20 years using water Cherenkov detectors.

Another technique, observing the atmospheric fluorescence from airshowers, is planned to complement the information obtained by the ground array. This method has been successfully employed for many years by the Fly's Eye experiment and by the Hi-Resolution Fly's Eye Prototype, which has been fully operational since April 1993. The optical technique measures the development of airshowers in the atmosphere. The energy of the particle which caused the shower is determined by the total amount of produced scintillation light. The types of primary particles can be inferred statistically from measurements of the depth in the atmosphere of shower maximum. These parameters will be combined with those measured by the ground array.

An additional optical technique which requires more development is the non-imaging detection of the Cherenkov light from air showers using solar panels. This technique shows promise as a possible third detector system which can provide complementary shower information 50-100% of the time.[7].

3 Scope of Proposal

This R&D effort will focus on continued development of detector concepts with the goal of producing and field testing production quality detector stations. We envision this to be a 2 year effort (1996 & 1997) of investigating 3 aspects of the equipment; 1) ground array detector R&D; 2) detailed radio & environmental surveys of the selected sites; 3) optical detector R&D.

4 Ground Array Component

Surface detector station R&D forms the major component of this proposal. We propose to set up a 7 station test cell centered on the CASA/MIA detector. Coincident events will be used to characterize the operation of the detector stations under realistic operating conditions. Each station will be a full scale prototype of the Auger Project reference design detector stations, including full size water Cherenkov tank, solar power, custom front end electronics, station controller, GPS timing, and spread spectrum radio transceiver. This 7 station cell can self trigger and will allow us to exercise all the essential features of the surface array, including alert logic, triggering, data readout, monitoring functions, station controller program loading, muon/EM component separation, event building, and event reconstruction. The 7 stations will be placed on a 500m triangular grid centered on CASA. This will yield one coincident event with CASA/MIA above 3×10^{16}eV every 2 hours, and a similar coincidence rate with the HiRes Fly's Eye during the time it is operating. The 7 stations will allow us to evaluate different water tank designs, phototube housings, and the like under extended field conditions.

Associated with each detector station will also be a solar panel air Cherenkov detector. Funding for the air Cherenkov detector development is not requested in this proposal. It is hoped that the NSF will fund this development work at the University of Utah.

The 500m station spacing is too close to adequately exercise the limits of the radio propagation. Therefore, we will install an additional 6 stations (without detectors) with 1500m spacing to ensure that the communications system is adequately exercised.

Electronics will be based upon VME 6U format. The small size facilitates rapid and relatively inexpensive development cycles. The VME standard allows migration from general purpose commercial electronics to more cost effective more highly integrated custom electronics where appropriate.

We envision this work to occur in several phases which are described below.

4.1 Phase 1 (1st 1/2 1996)

This phase involves preparations such as the design, construction, and testing of custom modules and the acquisition of commercial modules that are performed at the home institutions prior to setting up the test cell at Dugway. The tasks involved include:

(i) Design and acquire full size water tanks. We will want to acquire tanks of several designs in order to evaluate their performance in field conditions.

(ii) Acquire PMTs for water Cherenkov counters.

(iii) Acquire VME card cages and backplanes for the detector stations and radio only stations.

(iv) Design and build PMT bases and HV supplies and/or acquire commercial units.

(v) Acquire commercial VME DACs and ADCs for HV control and monitoring.

(vi) Acquire solar power systems.

(vii) Acquire commercial modules (*eg.* ADC) for solar power and environmental monitoring.

(viii) Acquire commercial GPS receivers.

(ix) Design and build GPS interface.

(x) Acquire commercial VME CPUs to use as station controllers.

(xi) Develop skeleton station controller code.

(xii) Acquire commercial transceivers and antennas.

(xiii) Analyze initial propagation measurements from the 2 selected sites provided by the site survey team.

(xiv) Design and build communications interface modules to commercial transceivers.

(xv) Begin design of custom transceiver alternative.

(xvi) Develop initial communications protocol.

(xvii) Design and construct front end electronics modules.

(xviii) Acquire central DAQ computer for the cell.

(xix) Acquire VME and OS-9 development system.

(xx) Acquire development tools and test instruments.

(xxi) Begin design of custom low power CPU module with solar & environmental monitoring, HV control and monitoring, GPS interface, and fail-safe reset.

(xxii) Acquire solar panels for atmospheric Cherenkov detector.

(xxiii) Design and build solar panel front end electronics.

4.2 Phase 2 (2nd 1/2 1996)

This phase involves the initial installation and operation of the equipment at Dugway. We plan to install 3 water tanks at this stage. Because they will be using a mix of custom and commercial electronics not optimized for low power operation, we will string AC power to these first stations. We will install radio transceivers and begin shaking down the communications network. The first stations will also have provision for local storage of data which will be used until the radio communications system becomes operational. The initial installation would include:

(i) 3 full size water tanks with PMTs.

(ii) Custom PMT base/HV supplies

(iii) Commercial VME card cages and backplanes for the detector stations.

(iv) Commercial VME DACs and ADCs for HV control and monitoring.

(v) Commercial GPS receivers.

(vi) Custom GPS interface.

(vii) Commercial VME CPU/station controllers.

(viii) Skeleton OS-9/OS-9000 station controller code.

(ix) Commercial transceivers and antennas.

(x) Custom communications interface modules.

(xi) Custom base communications protocol.

(xii) Custom front end electronics modules.

(xiii) Commercial central DAQ computer for the cell.

(xiv) Solar panels for atmospheric Cherenkov detector.

(xv) Custom solar panel front end electronics.

4.3 Phase 3 (1st 1/2 1997)

In this phase we will replace some of the commercial electronics with more highly integrated custom electronics. Four additional detector stations and 6 radio only stations will be installed. The radio communications system will be used for triggering and readout of the detector stations. Solar panels will be installed to power the stations. New items in this phase include:

(i) 4 additional water tanks.

(ii) 6 radio only stations separated by 1500m.

(iii) 2nd generation custom PMT base/HV supplies.

(iv) Custom low power CPU module with solar & environmental monitoring, HV control and monitoring, GPS interface, and fail-safe reset.

(v) Improved OS-9/OS-9000 station controller code.

(vi) 2nd generation custom communications interface modules.

(vii) Improved custom communications protocol.

(viii) 2nd generation custom front end electronics modules.

(ix) Commercial solar power systems.

(x) Repair/upgrade/retrofit to solve problems discovered in field test.

4.4 Phase 4 (2nd 1/2 1997)

In this phase we will have installed production quality electronics. New items in this phase include:

(i) 3rd generation custom PMT base/HV supplies.

(ii) 2nd generation Custom low power CPU module with solar & environmental monitoring, HV control and monitoring, GPS interface, and fail-safe reset.

(iii) Production quality OS-9/OS-9000 station controller code.

(iv) 3rd generation custom communications interface modules.

(v) Custom production communications protocol.

(vi) 3rd generation custom front end electronics modules.

(vii) Repair/upgrade/retrofit to solve problems discovered in field test.

5 Site Studies

This involves detailed terrain maps and radio surveys of the 2 selected sites. Detailed topographic information and proposed station siting will be used as input to 2d communications simulations. Radio surveys will be conducted to validate the simulations. Additional studies of the optical properties of the site will be performed. $25,000 of portable radio and optical monitoring equipment is required.

6 Optical Component

The fluorescence detector design is based on techniques which the Fly's Eye proved to be effective. The design can take advantage of development work which has been done for the High Resolution Fly's Eye (HiRes) and the Japanese Telescope Array Project. There are important features which are specific to the Auger Project, however, and these aspects require research and development work prior to any detector construction. Prototype components must be field tested to determine their reliability in all seasons of the desert environment. We expect the work specified below to be completed in 1.8 years after receiving funding.

The R&D materials and work are itemized here in three categories. The first category is testing the production, quality, and durability of mirror elements to be used in the Auger Project. The second concerns the design and prototype construction of support structures: mirror mount with adjustments, mirror enclosure and door, and a camera for holding and protecting phototubes against daylight, moisture, and large temperature variations. The final section is the study of PMT options. This involves testing numerous photomultiplier tubes from all manufacturers. We also anticipate our physicists working with suppliers in the design of a PMT with high quantum efficiency and uniform response across the tube face.

6.1 Mirrors

In order to detect cosmic ray airshowers incident on the Auger Detector ground array, F/1 mirrors of 4 meter diameter are needed. Studies carried out in the workshop indicate that in order for each mirror to observe approximately 16x16 square degrees with acceptable aberrations, a 4 meter mirror should be made of 19 small mirrors arranged in a way similar to that used in the Telescope Array (which uses 3-m diameter F/1 optics). HiRes experience indicates that the HiRes mirror thickness can be reduced. A reduction of glass thickness can simplify the mirror mount and also reduce the cost of mirror production. Prototyping of mirrors using thinner glass will require the following resources:

(i) New kiln (HiRes mirror facility has been moved. The kilns were not kept. The coating facility is being re-established).

(ii) Prototype ceramic mold (including machining, polishing, and controls).

(iii) Power installation (provided as university contribution)

(iv) Glass blanks

(v) Fabrication: kiln assembly and mirror production and testing.

6.2 Mirror Mount and enclosure

A mirror needs to be covered in the daytime, since it focuses 12 Kw of solar power, which can be very destructive. The HiRes shelter design, which encloses the PMT camera as well as the mirror and mirror mount, is deemed inappropriate for the 4 meter diameter mirrors since a scaled-up HiRes shelter would be extremely large and costly. We are considering a design which integrates a mirror enclosure with the mirror mount. A garage-style door will open to expose the mirror when the detector is operating. The camera will be protected as a separate unit with a motorized cover. Prototyping a mirror mount with enclosure and the camera unit will require the following items:

(i) Engineering design

(ii) Frame assembly, mirror mounting, and alignment checks

(iii) Doors (several models for testing) and controls

(iv) Mirror and frame enclosure

(v) Concrete work (provided as university contribution)

(vi) Camera and Cover

(vii) Mirror mount and camera installation (field work)

6.3 Phototube characterization

One of the most important requirements is that the gain across the photocathode be reasonably uniform, since the track reconstruction and longitudinal profile determination depend on knowing the received light intensity at each instant as the spot moves across the focal plane. The HiRes team has worked with several photomultiplier manufacturers to achieve PMT cathode uniformity. The behavior of PMT's under high light conditions (0.7×10^9 photons/s) needs to be examined. We propose to purchase candidate tubes from all four major PMT manufacturers to study cathode uniformity. From the results of this study, we will select and work with a subset of manufacturers to produce acceptable tubes. Once the tubes meet our acceptance criteria, we will purchase 150 tubes from at least two manufacturers for long-term field tests. Necessary resources for this work are the following:

(i) Photomultiplier tubes for review

(ii) PMT bases

(iii) Assembly, scanning, environmental cycling, and long term testing

(iv) Physicist time for the cooperative design of satisfactory phototubes

7 Dugway Operations

The operation of the test-cell will be done as independently of CASA/MIA operations as possible. The prototype system will be configured to record data when triggered either internally or from an external source such as the CASA/MIA, DICE, or HiRes experiments. This flexible triggering scheme is presently employed successfully among the various experimental elements at Dugway. The test cell will operate for 7-10 days each month, centered on the best HiRes operating nights.

One purpose of the test cell is to investigate the ability of the prototype detectors to distinguish different particle types (muon or electromagnetic). This is to be accomplished by comparing to the measurements of the same shower by CASA/MIA and/or HiRes on an event by event basis. We will tag each test cell trigger with its GPS time of occurrence and then match with the appropriate CASA/MIA and/or HiRes event off-line, after reconstruction. The present CASA/MIA system has demonstrated that this technique works with turnaround time of about 24 hours or less.

We note that the muon system (MIA) can also perform most of the above functions independently of CASA. In the event that the CASA array ceases operations in the future, MIA can, in principle, remain functioning as part of the test cell system.

Current funding for the operation of CASA/MIA expires at the end of February, 1997. Additional funds are requested in this proposal for utilities at Dugway to allow CASA/MIA to be operated from March through December 1997 for 7-10 days per month in conjunction with the test cell.

8 Travel

We consider in this section the travel requirements for this R&D effort.

We categorize the ground array work according to the tasks previously outlined in section 4. The majority of person-hours spent in installation at Dugway are incurred in Phases 2 and 3 of the plan. Phase 4 represents upgrades of the system. The installation, testing, and upgrading of electronics and software over the course of the test-cell project at Dugway will be done during periods that the ground array is running in coincidence with the HiRes Fly's Eye at the same location. These tasks will involve two people spending one week per month over the two years of the project.

The communication system development is being undertaken jointly by Michigan, Leeds, ENST (Paris), and Telstra Applied Technologies (Australia). This will require 2 trips of 2 week duration to Europe to work closely with our university colleagues at Leeds and ENST. Our foreign colleagues will also be traveling to the US for this work.

Surveying work will be done for both the Northern and Southern Hemisphere sites selected for the Auger Project. This task will have two people make four trips to each of the two sites. Each trip lasts two weeks. In this proposal we ask for funding for only one of these people since the other will be supported by foreign collaborators. Additional scientific staff for the survey work will be provided by institutions in the host countries.

There are then a total of 48 separate trips and 336 person-days at Dugway. The site-survey work will total 8 trips and 112 person-days, half of which are foreign travel. The communications R&D will total 2 foreign travel trips and 28 person-days. The costs of these trips are detailed in section 11 and are based on our experience operating at Dugway for many years.

9 Scientific Staff

Funding for critical scientific staff is requested in this proposal. We request funding for Ken Gibbs at the University of Chicago in 1996 and 1997 to continue his site survey work. Also, funding is requested in 1997 for Chicago technician Mike Cassidy to provide support at Dugway after normal CASA/MIA operations conclude in early 1997. The salary funding at Michigan for Research Scientists Dave Nitz and Jim Matthews currently ends at the end of February 1997. We request salary funding for them in this proposal for the last 10 months of 1997. We request funding for a Ph.D. thesis graduate student to work with Prof. Wayne Stark on the communications system R&D. At Penn State we request funding for a portion of 1 Postdoctoral Scholar who will spend 1/3 time on this project, and the other 2/3 doing NASA sponsored research. At Utah we request funding for 1/2 of Paul Sommer's salary. Paul is critical to the development of the optical component of the Auger Project. The other 1/2 of his salary is provided by the NSF for the HiRes project. We also request 2 months per year of engineer Stan Thomas' salary, and 8 months technician salary spread over the 2 year program.

10 Summary of Division of Responsibilities

10.1 US Universities

Many institutions will participate in the analysis and understanding of the data from the R&D program. However, primary responsibility for the various pieces of the R&D needs to be apportioned. The primary efforts of the 4 Universities participating in this R&D work are summarized in the following subsections.

10.1.1 University of Chicago

(i) **Site studies:** Perform, in conjunction with the French groups, site studies of the 2 selected sites, including detailed radio surveys and topographic maps for input to 2d radio propagation simulations.

(ii) **Local support:** Provide on-site technical support.

10.1.2 University of Michigan

(i) **Front end electronics:** Design and construction of custom front end modules, including custom ASICs where appropriate; procurement and evaluation of LeCroy supplied alternative if possible.

(ii) **Communications system:** Procurement, installation, and testing of commercial transceivers; implementation of custom interface to the commercial transceivers.

(iii) **Communications protocol:** Develop coding schemes, modulation schemes, and network protocol, in conjunction with Leeds, ENST, and Telstra groups. Support for a Ph.D student in EECS, supervised by Prof. Wayne Stark is requested in this proposal.

(iv) **DAQ system:** Work with the College de France group in developing the DAQ software; provide test cell data logging computer.

10.1.3 Penn State University

(i) **VME system:** Procure and install VME crates and environmenatal enclosures; design and construct power converters; coordinate integration of electronics supplied by other groups.

(ii) **GPS system:** Procure and install commercial GPS receivers; work with Leeds group on design and construction of multi-buffered GPS interface board.

10.1.4 University of Utah

(i) **Mirror making R&D:** Perform R&D on thin mirror fabrication for the fluorescence detector.

(ii) **Mirror mount and enclosure R&D:** Design and fabricate an integrated mirror mount and enclosure.

(iii) **PMT uniformity studies:** Study photocathode non-uniformity characteristics of various PMTs; assess implications for fluorescence detector.

(iv) **Solar panel Cherenkov detector:** Procure and install solar panels for Cherenkov detector; prove feasibility of such device. Direct funding for this research is not sought in this proposal.

(v) **Local support:** Provide local technical and administrative support.

10.2 Other Participants

Significant contributions will be made by other collaborating institutions not funded by this proposal. The Auger Project is an international effort. Our colleagues efforts are key in all phases of the project. We are happy to note that the French groups have secured funding from CNRS for the 1996 portion of their R&D program, and that the Argentinan groups also have a commitment of R&D funding.

Contributions to the R&D effort by institutions not included in this proposal are summarized below.

10.2.1 Fermilab

(i) **Water Tanks:** Design, procure, and install full size tanks for water Cherenkov detectors.

(ii) **PMTs, PMT bases, and HV supplies:** Select, procure, and install PMTs; design and construct PMT bases, HV supplies, and associated environmental housings; provide commercial and/or custom VME based HV control and monitor modules; procure, if possible, and evaluate commercial bases and HV supplies.

(iii) **Front end electronics:** Assist in design and implementaton of front end modules.

(iv) **Solar panel Cherenkov detector electronics:** Design and construct electronics for solar panel Cherenkov detectors.

(v) **Solar power system:** In conjunction with Argentina, acquire and install the solar power systems at Dugway; implement monitoring system using custom or commercial electronics.

(vi) **Mechanical integration:** Design and implement mechanical integration of solar power system, battery box, electronics enclosure, and antenna mast with water tanks. Design and implement antenna mast.

(vii) **Site studies:** Investigate and cost conventional utilities at the 2 selected sites; water, central power, roads, *etc.*

10.2.2 University of Leeds

(i) **GPS system:** Design and construct multi-buffered VME format interface to GPS receivers.

(ii) **Communications protocol:** Develop coding schemes, modulation schemes, and network protocol, in conjunction with Michigan, ENST, and Telstra groups.

(iii) **Custom communications system R&D:** Work with ENST group on development of custom transceiver.

10.2.3 Paris VI, College de France, ENST, Besancon

(i) **Station controller:** Develop low power station controller board.

(ii) **Slow control and monitoring:** Incorporate solar power monitor, HV control and monitoring, and GPS interface circuitry/functionality developed elsewhere onto custom station controller board.

(iii) **Station controller software:** Take prime responsibility for station controller software.

(iv) **Communications protocol:** Develop coding schemes, modulation schemes, and network protocol, in conjunction with Michigan, Leeds, and Telstra groups.

(v) **Custom communications system R&D:** Work with Leeds group on development of custom transceiver.

(vi) **Site studies:** Perform, in conjunction with the University of Chicago group, site studies of the 2 selected sites, including detailed radio surveys and topographic maps for input to 2d radio propagation simulations.

10.2.4 University of Adelaide, Telstra

(i) **Fluorescence detector R&D:** Participate in fluorescence detector R&D in conjunction with Utah group.

(ii) **Communications protocol:** Develop coding schemes, modulation schemes, and network protocol, in conjunction with Michigan, ENST, and Leeds groups.

(iii) **Communications system R&D:** Procure, install, and test radio transceivers in Australia; implement custom interface.

(iv) **Site studies:** Assist Chicago and French groups in survey of Australian site, if one is selected.

10.3 Argentina

(i) **Water tank studies:** Perform study of water purity longevity and freezing properties with various additives; design and construct full size tank prototypes. Install one or more tanks at Dugway.

(ii) **Solar power system:** Provide solar power system components for cell test at Dugway.

(iii) **Site studies:** Assist Chicago and French groups in survey of Argentinan site, if one is selected.

10.4 Japan (ICRR)

(i) **Fluorescence detector R&D:** Study Telescope Array as fluorescence component for one Auger Project site.

10.5 China

(i) **Water tank R&D:** Design and construct full size water tank prototypes. Install one or more tanks at Dugway.

(ii) **PMTs:** Provide Chinese PMTs for evaluation.

10.6 Russia

(i) **PMTs:** Provide Russian PMTs sufficient to instrument 5 water tanks at Dugway.

11 Budget Discussion

We have structured the budget for this multi-university proposal with the University of Michigan as the lead institution. The University of Chicago, Penn State University, and the University of Utah are sub-grantees. This is reflected in the budget pages (ER 4620.1) and budget explanation pages for the University of Michigan for 1996 and 1997 which include the total project funding request. Each sub-grant is in turn delineated by a set of budget pages and budget explanation sheets.

The University of Michigan has agreed to exempt from indirect costs the fabrication of the test cell electronics systems ($108,563 in 1996, $91,434 in 1997). This represents a reduction of $104,456 in indirect costs. We also note that University seed support during 1995 from the Office of the Vice-President for Research, the College of Literature, Science, and the Arts, and the Department of Physics made possible the preparation of the proposal.