Initiating the Detector Deployment for a Currently Planned NASA Accelerator Measurement

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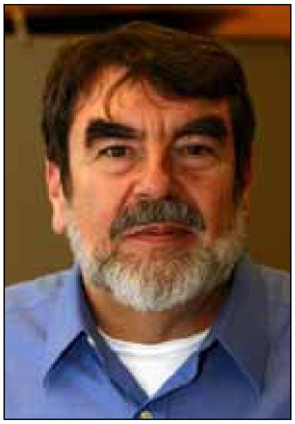
Abstract—Investigators initiated critical efforts for the development of a proposal to NASA in response to NRA NNH042UU005N, which has been approved and for which funding is currently pending. Supported in part by ISSO funding, data were taken with *C, Si,* and *Fe* beams of 3, 5, and 10 GeV/A, each incident on *C, Al, Fe,* and *Cu* elemental targets. Preliminary results from the ongoing analysis of data are reported here. Seven grants totaling more that $2,400,000 have been awarded from proposals whose writing was enabled, in part, by current and prior ISSO support. In addition, ISSO support has resulted in the publication of more than 35 papers and presentations worldwide.



Dr. Lawrence S. Pinsky

ISSO funding enabled Dr. Lawrence S. Pinsky to initiate critical efforts that are the subject of funding now pending on a proposal submitted to NASA in response to NRA NNH04ZNH005N. This ISSO mini-grant enabled Dr. Pinsky to participate in measurements at the Alternating Gradient Synchrotron (AGS) facility in New York this past July (2005) by employing existing UH detectors. The increased measurement capability that the UH detectors offered was essential to the efficient use of the accelerator beam time. Data obtained will significantly expedite the development of the various transport codes.

NASA created several physics-related consortia under the general moniker of Space Radiation Shielding Consortia. Two of these consortia are specifically charged with the measurement and modeling of the heavy ion cross sections needed to simulate the transport of the constituents of the Space Radiation environment through shielding materials. Dr. Pinsky is a member of the "Modeling" Consortium.

Past ISSO funding has enabled Dr. Pinsky to successfully argue that NASA needs to support measurements of various heavy-ion interactions over a range of energies that span the region around 5 GeV/A. The essential problem for NASA in its quest to be able to accurately predict the nature of the radiation field within spacecraft and on the lunar and planetary surfaces is the need to accurately model any nucleus-nucleus collision over the range of all energies likely to be encountered in the space environment because of the presence of every element of the periodic table in the Galactic Cosmic Ray (GCR) spectrum.

The problem is made somewhat more tractable by the fact that the abundance of all elements heavier than iron (*Fe*) is minimal. Even so, the number of potential target and projectile combinations is very large, more so when coupled with the need to model those interactions over the energy range from the threshold for such reactions below 100 MeV/A up to about 10 GeV/A. The steepness of the energy spectrum is sufficient to make events above that energy statistically less important.

The difficulty is that this range of energies spans the most important changes in relevant physics processes. At the lower limit, non-relativistic approximations remain valid; near the upper limit, however, relativistic effects dominate. Over the same energy range, the relative importance of nuclear structure changes from a dominating effect at the lower energies to one of less importance simply because the total energy of each constituent dominates the nuclear energy levels as the incident energy rises. Finally, this is also the energy range where the effects of major inelastic channels, such as the advent of meson production and its resonant behavior, enter the picture and must be included in the models.

Given these practical difficulties, it is not surprising that no acceptable general model of these interactions has been produced. In fact, the approach has been to develop multiple models, each of which is focused on representing the details of specific portions of the energy range. Current models employed by researchers to model this region have a crossover now arbitrarily set to occur at 5 GeV/A. Unfortunately, the detailed kind of data on hand needed to develop and benchmark such models is also unfortunately very limited. To that end, NASA has seen fit to create a Space Radiation Shielding Measurement Consortium to make the needed measurements. That consortium is led by a group from the Lawrence Berkeley Laboratory (LBL) headed by Dr. Jack Miller. In the past, LBL researchers have focused on measurements at energies well below the 5 GeV/A region. Based in part on advocacy by Dr. Pinsky, NASA decided to provide beam time this past summer (2005) at the AGS facility at BNL to make a series of measurements at 3, 5, and 10 GeV/A.

While this was a welcome step, the detectors that the BNL group had on hand were, unfortunately, quite limited, and there was no time for them to acquire more. The AGS is a unique facility in terms of its ability to deliver heavy-ion beams at these energies. Immediately after the opportunity this past summer, the machine with its experimental floor was to have entered a long, pre-planned period of rebuilding and reconfiguration. As such, Dr. Edward V. Hungerford, UH professor of physics, offered the use of some of his existing *Si*-Strip Detectors (SSDs) and proposed deploying these additional detectors in order to enhance the information that was to be taken during these AGS measurements. That offer was gratefully accepted by NASA and funding provided to support that effort under NRA NNH042UU005N. That proposal has been approved, but funding plans are still pending while NASA is currently engaged in a reorganization.

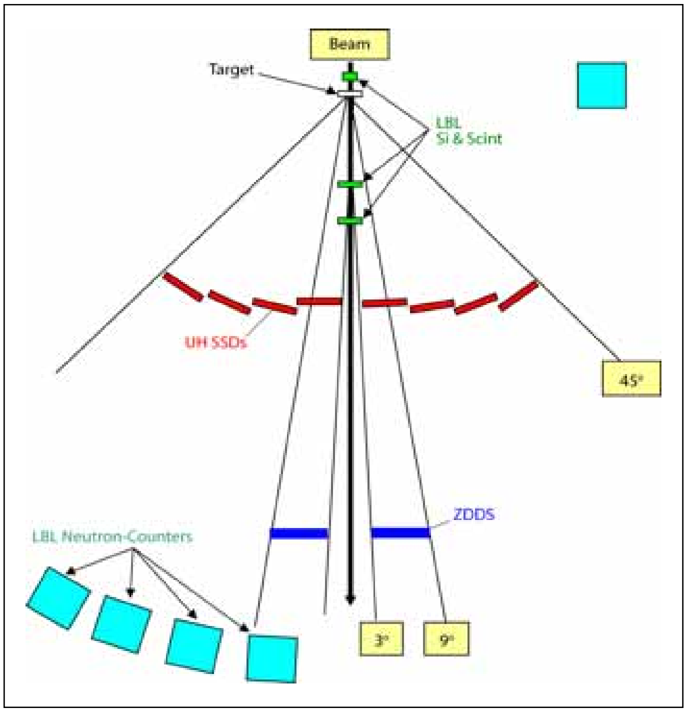


Figure 1. Detector Layout for AGS Measurements

Experimental Setup at the AGS

All detectors were deployed in the horizontal laboratory plane with the UH detectors at about 50 cm downstream of the target and the ZDDS another 50 cm behind them. The neutron detectors were arranged at a number of forward angles as well one backward angle at varying distances up to ~10 m downstream of the target. There was a single 1 cm^2 scintillator upstream of the target to define the beam location and acceptance.

In order to address this discrepancy in an energy regime of importance to the assessment of dose effects from space radiation, as noted previously, NASA sponsored the measurement of the reactions from heavy ion beams incident on thin elemental targets. Because of the planned imminent shutdown of the AGS experimental floor for an extensive and extended reconfiguration program, NASA elected to have the measurement performed with the detector systems that were readily on hand. As depicted in Fig. 1, these included small scintillators and monolithic *Si* detectors supplied by the LBL Group for use along the beam-line in the forward direction to measure the charge of the forward-going fragments with good resolution. These detector elements were deployed with respect to the target so as to cover the forward-most direction within three degrees of the beam-line. In addition, that group supplied five individual neutron detector systems, which were deployed in the horizontal lab frame at a variety of scattering angle locations in both forward and backward angles.

The MSFC Group supplied the Zero-Degree Detector System (ZDDS), which in this application is a bit of a misnomer. This detector consisted of an array of sixteen 8 cm × 8 cm *Si* pad detectors configured in a double layer with eight squares in each layer arranged in a 3-by-3 square pattern with the central square vacant to allow the beam particles to pass through. This detector system also included its own masking scintillator for trigger purposes. Each 8 cm × 8 cm square was itself further subdivided into sixty-four 1 cm × 1 cm individually read-out pads. The charge resolution of each pad was sufficient to resolve individual elements from protons through at least *Fe*. This detector system was deployed sufficiently far downstream of the LBL beam-line detectors (~1 m downstream of the target) so that the ZDDS central hole was just masked by the LBL detector acceptance, covering the laboratory scattering angle from ~3 degrees through ~9 degrees.

Finally, the University of Houston Group provided eight 5 cm × 8 cm *Si* strip detectors, each with 144 strips running parallel to the 5 cm side. These were arranged into staggered arcs of four detectors each at ~50 cm downstream of the target. The inner edge of each arc began at ~3 degrees with the corresponding outer edge reaching ~45 degrees. These detectors were read-out with TDCs only, so that no charge information short of threshold acceptance was available. Thus, only time and location information is available from this research. Because of a shortage of TDC modules, the outer three detectors in each arc were multiplexed with each three successive contiguous channels being ganged together. The innermost detector in each arc had each individual strip read-out. The location of the arcs caused them to overlap the lateral acceptance of the ZDDS detector system so that the latter could be used to check the efficiency of the *Si* strip detectors as a function of particle charge.

Given the separate nature of each system, each has its own data acquisition system. The ZDDS, having had its read-out electronics designed for balloon-flight payloads, had a very low maximum data rate (~100 Hz). LBL detectors were limited by their electronics to a maximum rate of several thousand Hz as a practical matter due to dead-time considerations. The UH detectors were the fastest with an ability to sustain well upwards of 10-100 KHz continuously, with the added capability of multi-hit

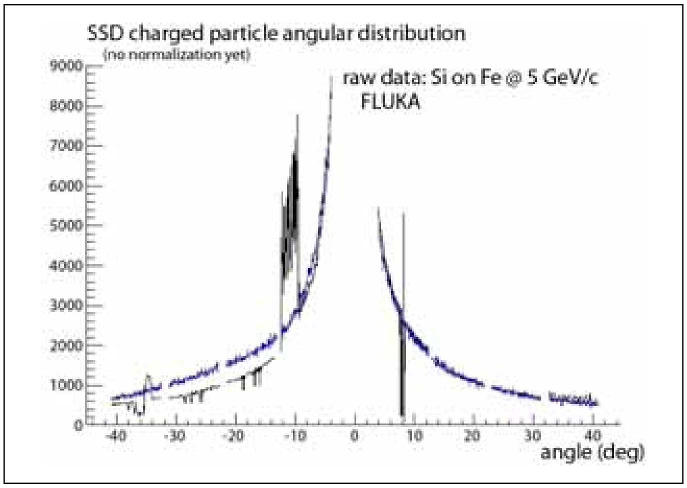


Figure 2. Raw data are shown in black for 5 GeV/A *Si* incident on an *Fe* target. The FLUKA results, arbitrarily normalized, are shown in blue. Some noisy channels are clearly visible and can be removed during the analysis.

TDCs with 10 ns resolution during their active time. To simplify matters, LBL Detectors were set to trigger on each beam particle (some runs were taken with this trigger pre-scaled to control dead-time effects on the ZDDS and neutron triggers). The existence of either a Neutron trigger or a ZDDS trigger was noted in scalars in both the LBL and UH read-out sequences. Two separate scalers were used in each system for synchronization purposes. One scaler was reset at the beginning of each beam spill and the other only at the beginning of each run. A 1 KHz clock was fed to each scaler; the run scaler also had a channel incremented at the beginning of each spill. Neutron and ZDDS triggers were noted in both scalers as well.

Preliminary Results from the July Run

Data were taken for common fixed beam rigidities at each nominal beam setting. In sequence, we took data at ~5 GeV/A, then at ~10 GeV/A, followed by the data at ~3 GeV/A. At each energy setting, a sequence of three different beams was supplied: *C*, *Si*, and *Fe*. Finally, the same sequence of elemental target materials was employed for each beam energy/species combination, and their thicknesses were adjusted to maintain ~ 0.5 interaction lengths in each case. The elemental targets consisted of *C*, *Al*, *Fe*, and *Cu*. These were chosen to provide both symmetric and asymmetric reactions in a collection that would allow evaluation of the kinematic inverse of as many of the interactions as possible. Approximately 1.5 million beam triggers were taken at each beam energy/beam species/target species combination. In addition to these elemental targets, data were taken for each combination with several compound thick targets including polyethylene.

This report provides only preliminary results from the initial quick-look analysis of the UH *Si* strip detectors. The analysis is ongoing and will eventually include the full exclusive event reconstruction of the data from all four detector systems.

Figure 2 shows a plot of raw hits from the UH *Si* strip detectors as a function of the scattering angle, as measured from the center of the target. Both the left and right detector arrays are shown separately. Also superimposed on the raw data is an arbitrarily normalized prediction from the current version of FLUKA. This simulation was done using FLUKA in its standard configuration wherein both of the event generators (RQMD & DPMJET3) in the Monte Carlo runs were used as mutually exclusive alternatives randomly selected using a linear crossover scheme stretched over the 4-6 GeV/A range. In this scheme, RQMD starts out at 4 GeV/A being used 100% of the time, linearly decreasing in probability to 0% at 6 GeV/A, with DPMJET3 providing the opposite. Thus, in an event where a fragmentation of the initial beam particle occurs in the target and one or more of the fragments also has a subsequent interaction, the first may have been evolved using one of the event generators with the subsequent interaction using the other being evident. Because these data do not yet include any timing cuts, some of the noise may be removable. The asymmetry is due to a slight offset in the detector.

It is clear from the data in Fig. 2 that the *Si*-strip detectors were offset slightly to one side with respect to the beam centerline, as defined by the beam-trigger scintillator. The Monte Carlo was arbitrarily offset iteratively to approximate the asymmetry in the data. It is clear that the current event generators do a reasonable job of reproducing this preliminary angular distribution in shape, but with some slight observable differences.

It is also clear that at least one of the cards was noisy. It is hoped that once the TDC information is used to cut the data, this noise will be reduced. From fundamental physics we know that the data must be symmetric, and, as such, we can use the combination of both sides to obtain a corrected angular distribution. We look forward to being able to produce separate angular distributions for selected fragmentation final states.

Publications

Pinsky, L. S., et al. "FLUKA Status and Results from the High Energy AGS July Run," IEEE *Proc*., of the Aerospace Conf., Big Sky, MT, March, 2006. (*To be published*.)

Presentations

Pinsky, L. S., et al. "FLUKA Status and Preliminary Results from the High Energy AGS July Run," Workshop on Radiation Monitoring on the Intl. Space Station (WRMISS-2005), Chiba, Japan, Sept. 7–9, 2005.

Funding and Proposals

"Measurements of Fragmentation Cross Sections and Particle Spectra For Galactic Cosmic Ray-Like Nuclei between 3 and 10 GeV/nucleon at the BNL AGS," NASA, UH: $100,000. (*Submitted*.)

"Radiation Environment Model for the Inner Heliosphere," NASA, UH: $554,000. (*Submitted*.)

"Space Radiation Shielding," NASA, 2003–2006, $687,000.

Thesis

Elkhayari, E. "Measurement of Elemental Cross Sections for *C*, *Si*, and *Fe* at 3, 5, and 10 GeV/A," UH, Jan. 2005–present.