Proceedings of ICRC 2001: 134 © Copernicus Gesellschaft 2001

ICRC 2001

Reanalysis of energy spectrum and composition in the DICE experiment

C. G. Larsen[1]**, D. B. Kieda**[2]**, and S. P. Swordy**[3]

[1]Department of Computer Science, Dixie State College of Utah, St. George, UT 84770, U.S.A.
[2]Department of Physics, University of Utah, Salt Lake City, UT 84114, U.S.A.
[3]Enrico Fermi Institute, Department of Physics, and Department of Astronomy and Astrophysics, University of Chicago, Chicago, IL 60637, U.S.A.

Abstract. Possible systematic errors in the DICE energy spectrum and composition results are explored. The corrected data will be presented at the conference.

1 Introduction

The Dual Imaging Cerenkov Experiment (Boothby et. al.) (DICE) has produced energy spectrum and composition results near the knee (Swordy and Kieda, 2000). These results showed an increase in the protonic component as the knee is approached, consistent with the results expected from a saturation of the propagation path length to a constant value above a certain energy (Swordy, 1995). Recent measurements by BLANCA (Fowler, et. al., 2000) indicate a similar increase in the proton component approaching the knee, followed by a rapid shift towards an iron dominated composition. See Figure 1.

Some possible systematic errors were not accounted for in the initial analysis. These include mirror spot size, dead space between photomultiplier tubes (PMTs), and electronic saturation.

2 Correction Factors

2.1 Mirror Spot Size

The mirrors used to focus the image into the focal plane have a spot size due to spherical aberrations and surface imperfections. This effect will cause the light received from a particular direction to be dispersed over a small area of the focal plane, rather than focused at a single point. Figure 2 shows the spot size effect for 2 sets of parallel photons, one vertical and one 5 degrees from vertical. The hexagons represent the pixel size in the focal plane. The large Xs illustrate the location of photons without a spot size.

Correspondence to: C. G. Larsen (cgl@dixie.edu)

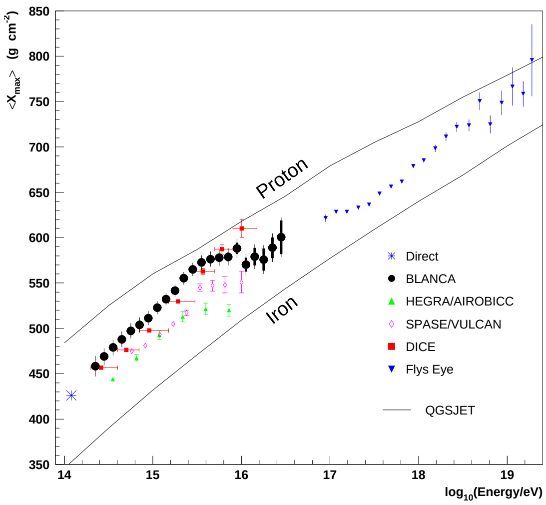

Fig. 1. Recent X_{max} measurements (Fowler, et. al., 2000)

The spot size does not produce a large change in the energy resolution of the DICE detector, since all of the light is still collected and used to calculate the primary energy. However, since the spot size changes the distribution of photons across the focal plane, it can cause shifts in X_{max}.

2.2 Dead Space

DICE uses hexagonal PMTs laid out in a 16 x 16 grid. The tubes are tightly packed together, however, small gaps exist between their edges. Also, the glass on the edges of the tubes has a finite thickness where a loss of sensitivity occurs. Photons that reach the focal plane in these gaps are not integrated into the event signal by DICE. In Figure 2 the gaps between the hexagons are representative of the dead space. Each tube face is 40mm from flat to flat, and the average dead space between tubes is 6mm.

DICE predicts the energy of the primary particle based on

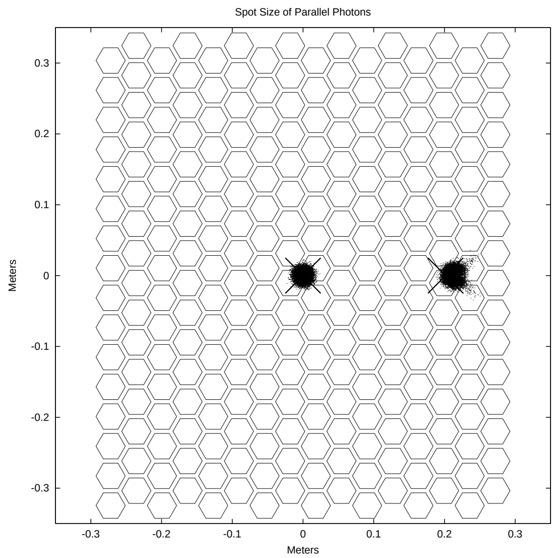

Fig. 2. Mirror Spot Size

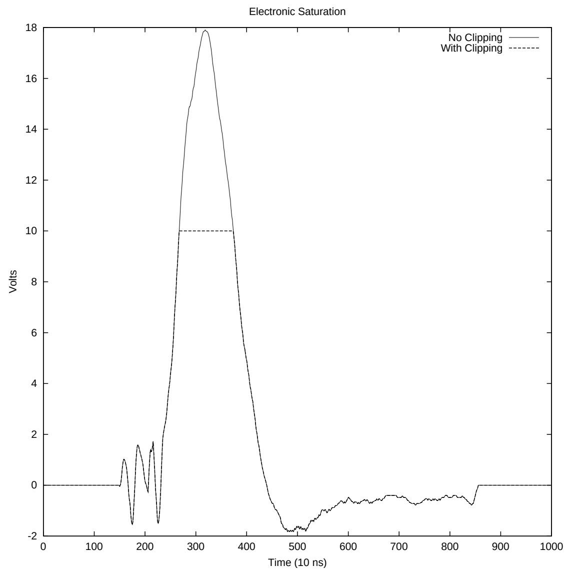

Fig. 3. Wave Forms are Clipped at 10 Volts

the total amount of light collected for an event. Since the dead space problem causes some light to be lost, this will cause the energy predictions to be too low.

2.3 Electronic Saturation

As the electronic signal is brought from the PMT into the preamplifier and other electronics, 2 types of saturation may occur. 1) Any signals greater than the preamplifier maximum of 10 volts are clipped, and large pulses will cause a large negative tail to be generated. This clipping of high voltages and tail will be integrated with the positive portion of the wave, reducing the charge integral. Figure 3 shows this effect.

2) The charge digitization circuits are limited to 12 bits, or counts of 4095. It is possible for the total area of the integral to exceed this amount, producing another loss of charge. This type of saturation is rare.

Both of these saturation effects cause the energy to be under estimated due to charge loss. Since saturation will occur in tubes with strong signals, and these tubes are likely to view the portion of the shower at X_{max}, this may also shift the calculated depth of shower maximum.

3 Simulation

These systematics have been studied by air shower and detector simulations to determine the magnitude of corrections needed. Each of the systematics may be enabled or disabled to allow for the effect of each to be isolated or for their combined effects to be studied. Each simulated event is tested with all 8 possible effects combinations.

3.1 Air Shower Simulation

The air showers are simulated using a version of Hillas's MOCCA (Hillas, 1987) modified to calculate the cerenkov emissions from the shower and store them in a data file for further study. Cerenkov emission data are stored for each relativistic particle in steps of not more than 50 meters. The data stored includes the particle position and direction of travel, the time of emission, the cerenkov cone angle, and the amount of energy emitted as cerenkov radiation.

3.2 Optical Simulation

The optical simulation reads the data output from MOCCA, creating rays of photons on the cerenkov cone, and distributing the cerenkov energy among the rays. The cerenkov radiation is ray traced from the point of creation to the surface of the detector mirrors, with an atmospheric transmission factor applied.

Only photons that impact on a mirror surface are kept at this stage of the simulation. The PMT cluster box's physical location is used to absorb photons that would impact the back and sides of the cluster assembly.

At the mirror surface, 2 types of reflection can be used. First the idealistic case of perfect direction preservation is used to reflect the photons. Second, a realistic model of the clover-leaf shaped spherical mirror with small surface imperfections is used to reflect the photons.

After reflection, the photons are ray traced to the focal plane of the mirror where the PMT cluster face is located. Each photon packet is placed in a PMT based on the geometric location of the packet at the cluster interface. When the dead space calculation is disabled, all photons are accepted into PMTs. When it is disabled, the photons that fall in the gaps between tubes are discarded.

The photons collected at each PMT are collected into a light profile as a function of arrival time. Each tube in the simulation has been given a unique photon to electron gain. This gain is then applied to the light profile to create a charge per time waveform. The gains of the simulation PMTs have been generated to produce a gain distribution similar to that of the actual PMTs based on detector calibrations.

3.3 Electronic Simulation

The charge per time waveform is used as the input into the electronic simulation. Here the charge per time is converted to voltage according to the resistance of the preamplifier circuit inputs. This waveform is then used as input to an impulse convolution function that was obtained from measurements of the detector electronics.

The electronic saturation effect is applied at this stage by clipping each voltage bin of the waveform that is greater than 10 volts.

The waveforms of all of the channels that received signals are analyzed to determine the time of the event trigger. The total charge of each triggered channel's signal is calculated by summing all of the charge in the output waveform over the integration window.

Each simulated channel is given a unique electronic gain and offset so that the gain and offset distributions are similar to those of the detector. These factors are applied to the channel's charge integral, then the resultant integral is digitized into a 12 bit signal.

The pattern of channels within each detector that trigger are analyzed to determine if a detector trigger would result. The trigger patterns match those of typical DICE operations. If the detector triggers, then an event is written to a datafile of the same format as the real data to allow the normal analysis routines to be used on the simulated data.

3.4 CASA Simulation

The DICE analysis code makes use of the event arrival direction and core position as detected by CASA. The event simulation generates artificial CASA data to match the appropriate direction and core position of the event. Again the data output from the simulation is identical in format to the real data to allow for standard analysis to be performed on the data.

3.5 Reconstruction

The simulated events are processed by the standard analysis software to insure that the analysis is identical to that of the real data. This software processes the events by reversing the electronic and PMT gains to calculate the number of photoelectrons and thus the amount of energy deposited on the face of each PMT.

This energy is then histogramed into a profile measured as a function of shower depth. This curve is fit to find the depth of shower maximum. The total amount of light is used to calculate the shower energy.

4 Conclusion

The corrections to these systematic errors are currently being studied. The corrected X_{max} distribution and energy spectrum for the DICE experiment will be presented at the conference.

Acknowledgements. This work was supported by the University of Utah, the University of Chicago, and by NSF Grant # PHY 9514193.

References

Boothby, K., et. al., Nucl. Phys. B (Proc. Suppl.) 52B, 166.

Swordy, S. P. and Kieda, D. B., Astroparticle Physics, 13, 137, 2000

Swordy, S. P., Proc. 24th Int. Cosmic Ray Conf., Rome, 2, 697 (1995)

Fowler, J. W., et. al., preprint astro-ph/0003190, accepted in Astroparticle Phys., 2000

Hillas, A. M., Mocca Monte-Carlo shower simulation, 1987