Strategy for Composition Measurements with SPASE

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1 Introduction:

The current South Pole Air Shower Experiment [Dickinson *et al.*, 1999a], in combination with AMANDA [Hill *et al.*, 1999], is a three-component air shower detector. The SPASE-2 scintillator array samples the shower at ground level, thus providing the information to reconstruct the trajectory of the shower and give a measure of its size or energy. (The latter is $S(30)$, the equivalent density of minimum ionizing particles at 30 meters from the shower core.) The VULCAN air-Cherenkov subarray [Dickinson *et al.*, 1999b] samples the pool of atmospheric Cherenkov radiation generated predominantly by particles in the region of shower maximum. This provides a measure of total shower energy and (from the lateral distribution) the depth of shower maximum (X_{max}). Finally, the signal in AMANDA provides a measure of the number of muons with sufficient energy to penetrate 1.5 km of ice ($E_\mu \geq 500$ GeV).

Corresponding to the three components of the experiment, there are three principal pairs of observables that are sensitive to composition, as listed in Table 1. In all cases, SPASE information is needed for each shower to determine its geometry. In the first case the shower size itself (represented by $S(30)$) is also one of the variables used in the analysis. The first and third methods are related to each other, but the last is more direct. The paper [Dickinson *et al.*, 1999c] gives preliminary results of the second method.

Table 1: Acceptance for SPASE coincidence experiments

Observables	(Detectors)	Time-averaged geometrical acceptance
$S(30)$ vs. μ-signal	(SPASE-AMANDA)	125 m^{2}sr
X_{max} vs. $E_{primary}$	(VULCAN-SPASE)	120 m^{2}sr
$E_{primary}$ vs. μ-signal	(VULCAN-AMANDA-SPASE)	5 m^{2}sr

For all three cases, interpretation of the data in terms of energy-dependence of the elemental abundance of the primary cosmic rays depends on Monte Carlo simulations. In this situation, having an overconstrained set of observables is helpful to resolve uncertainties in the calculations. For the subset of events that are triple coincidences, one has two independent determinations of the primary mass with the same data set, which can be compared with each other. One determination is from the muon signal as a function of primary energy (or $S(30)$) and the other from X_{max} vs energy. In addition, VULCAN-SPASE coincidences can be used to study experimentally the distribution of $S(30)$ for fixed primary energy and *vice versa*. This information can then be used to refine the analysis of the SPASE-AMANDA data.

2 Event Rates and Energy Range

The maximum energy that can be explored with each set of variables is determined by statistics, which in turn is determined by the coincidence rates and duty factors of the various components of the experiment. For energies sufficiently high that the trigger efficiency of SPASE2 is 100%, the rates can be estimated from the geometrical acceptance of each combination of detectors convolved with the primary spectrum and the appropriate duty factor.

Given the acceptances listed above and the spectrum as measured in the knee region [Amenomori *et al.*, 1996] event rates are summarized in Table 2 for $E_{primary} > 300$ TeV. Above this energy, SPASE is fully efficient, and showers within the perimeter of the array are well-measured.

Table 2: Coincident event rates in SPASE

Minimum energy (TeV)	300	1000	3000	10,000
Rate per year in 120 m^2sr	52,000	6700	860	80
Rate per year in 5 m^2sr	2200	280	35	3

3 Comments

The time-averaged acceptance for triple coincidences is too low at present to have significant statistics beyond the knee of the spectrum around 3000 TeV. Thus the strategy is to cross calibrate with triple coincidences below the knee then use the two independent sets of double coincidences to study the knee region.

The coincidence rates involving the under-ice detector will double after AMANDA-II [Halzen, 1999] is completed in 2000, and 100% of SPASE-VULCAN events would be seen by a kilometer-scale detector installed in the ice. In addition, the relative rates of triple coincidences can be increased if the duty cycle for the atmospheric Cherenkov subarray can be increased.

The AMANDA detector has a large dynamic range for response to muon bundles based on the energy deposited by the muons as they pass through the detector. There are several measures of AMANDA signal size at each optical module (hit or no hit, ADC value and time-over-threshold value). Given the large number of modules and the large size of AMANDA, together with the trajectory determined by SPASE and the ability to see outside the detector, it is possible to measure the number of muons via the lateral distribution of radiated Cherenkov light.

References

Amenomori, M. *et al.* 1996, Ap.J. 461, 408.
Dickinson, J.E. *et al.* 1999a, submitted to NIM.
Dickinson, J.E. *et al.* 1999b, submitted to NIM.
Dickinson, J.E. *et al.* 1999c, OG 1.2.05, these proceedings
Halzen, F. *et al.* 1999, HE 6.3.01, these proceedings
Hill, G. *et al.* 1999, HE 6.3.02, these proceedings