Composition Results at the Knee from CASA-BLANCA

L. F. Fortson[1], J. W. Fowler[1], C. H. Jui[2], D. Kieda[2], R. A. Ong[1], C. L. Pryke[1], P. Sommers[2]
[1]*Departments of Physics and Astronomy, University of Chicago, Chicago, IL 60637, USA*
[2]*Physics Department, University of Utah, Salt Lake City, UT 84112, USA*

Abstract

We present preliminary results on the energy spectrum and composition of cosmic rays between 0.3 and 30 PeV from the CASA-BLANCA experiment. The technique relies on measurements of the lateral distribution of air shower Cherenkov light. It is shown that conversion of the experimental data to a mean depth of shower maximum is highly independent of the choice of nuclear interaction model. The mean primary mass is also inferred directly from the measurements, and $\langle \ln A \rangle$ plotted for a number of hadronic interaction models.

1 Introduction

BLANCA consists of 144 angle-integrating Cherenkov detectors distributed throughout the CASA surface array in Dugway, Utah (Cassidy et al., 1997 and Borione et al, 1994). BLANCA measures the lateral distribution of Cherenkov light around the shower core position determined by CASA. This lateral distribution indicates both the mass and the energy of the primary cosmic ray through its shape and intensity, respectively. To interpret BLANCA measurements, we have run extensive CORSIKA shower simulation libraries, and developed a detailed simulation of the experiment's optical and other properties as described in OG 4.4.13 and OG 4.4.12 respectively.

The data presented here include air showers observed from January 1997 through May 1998, the entire operation period of the complete BLANCA array. The results in this paper use 400 hours of observation during the clearest weather, which represents about three-quarters of the recorded data. Individual showers were required to have a reconstructed core position at least 30 meters from the edges of CASA, to ensure good core location accuracy. Primary directions were restricted to within 7° of zenith to ensure only a small fraction of the Cherenkov light fell beyond the Winston cone cutoff angle of 11°. After making these cuts, the total exposure in the data set is 1.02×10^{10} m$^2\cdot$ sr$\cdot$ s. The CASA array trigger is fully efficient for showers above 300 TeV.

2 Energy Spectrum

Figure 1 shows the differential energy spectrum determined from BLANCA data. The transfer function relating measured parameters to primary energy is extracted using CORSIKA simulations processed through a full detector simulation (OG 4.4.13). The results depend somewhat on the interaction model used: QGSJET, VENUS, SIBYLL, or HDPM. Statistical error bars are shown only for the QGSJET model but are similar for all four interpretations. The main difference among the models is a shift in the energy-Cherenkov intensity relation; HDPM gives approximately 12% higher energies than SIBYLL with VENUS and QGSJET in-between. This fully accounts for the diagonal displacement of the four derived spectra from one another.

The absolute intensity calibration of the BLANCA detectors can also shift the spectra in Figure 1 diagonally. We measured the sensitivity of several detectors in a laboratory dark box using a stable, fast-pulse blue LED. The LED light source intensity itself was calibrated by counting single photoelectron pulses in a high performance reference photomultiplier. Gain variations over time were corrected by assuming a constant integral cosmic ray flux. We estimate that the intensity calibration has a systematic uncertainty of about 20%. This makes it a more important source of error than disagreement among the Cherenkov production of the various hadronic models.

Regardless of the energy scale, all four interpretations clearly demonstrate the "knee" in the cosmic ray spectrum. We observe the power-law index changing slowly over at least half a decade in primary energy; a

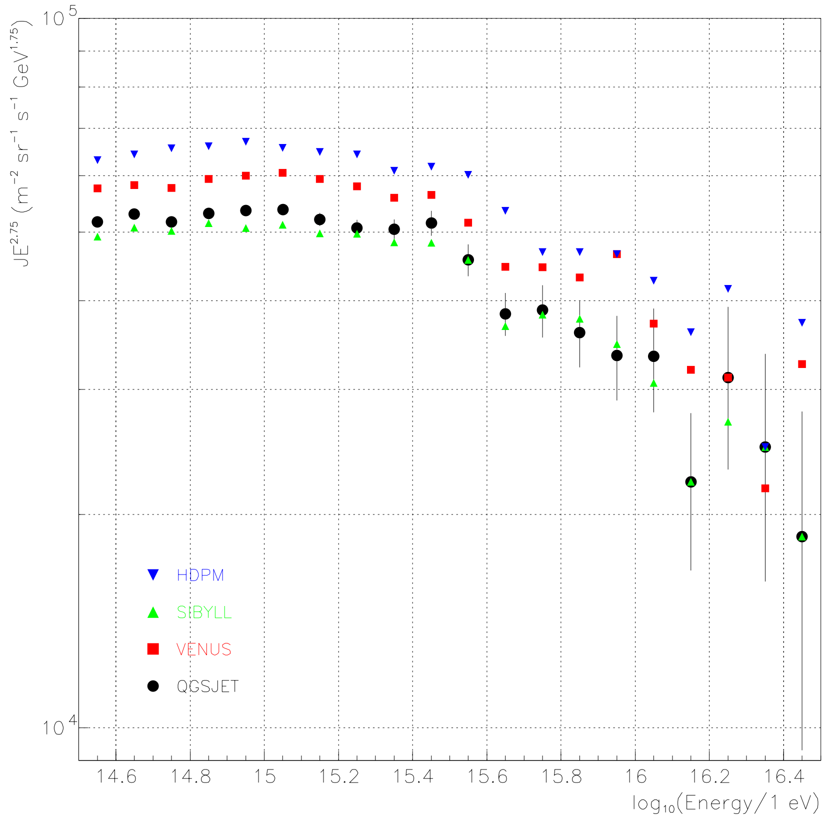

Figure 1: Preliminary BLANCA energy spectrum extracted using several interaction models.

much smoother steepening of the spectrum than some other experiments have reported (for example Nagano et al, 1984). The best-fit values of the indices are -2.7 below the knee and -3.1 above. The data are consistent with a knee position between 2 and 3 PeV.

3 Composition Results

Figure 2 shows the correlation between the CASA observable $\log_{10}(N_e/N_\mu)$ (log of electron to muon number ratio) and the BLANCA observable s (inner slope of the Cherenkov lateral distribution). Both parameters are expected to be sensitive to composition and their correlation increases confidence that the experiment is operating correctly.

Figure 3 shows mean X_{max} versus energy for the BLANCA data extracted on the basis of four hadronic models. BLANCA does not measure the depth of shower maximum (X_{max}) directly, as a Cherenkov telescope might. However the slope of the lateral distribution is strongly correlated with this quantity (Patterson, 1983). We convert slope to X_{max} using a polynomial fit to the results of CORSIKA showers processed through a full detector simulation (OG 4.4.13). All four models agree to within 20 g cm^{-2}, so the four sets of data points are very similar. However, the models differ substantially in the X_{max} predicted for showers of a given primary type. The bands in Figure 3 depict the error on the mean X_{max} for pure samples of proton and iron air showers.

Figure 4 shows the mean natural logarithm of the atomic mass $\langle \ln A \rangle$. The transfer function relating measured parameters to $\ln A$ is extracted using CORSIKA simulations processed through a full detector simulation (OG 4.4.13). Due to the large intrinsic fluctuations, the shower-by-shower resolution is of course poor; however, the procedure produces the correct $\langle \ln A \rangle$. As with the mean X_{max} results, the four hadronic models differ in their interpretation of the BLANCA data. However, they all agree on the trend; that the average

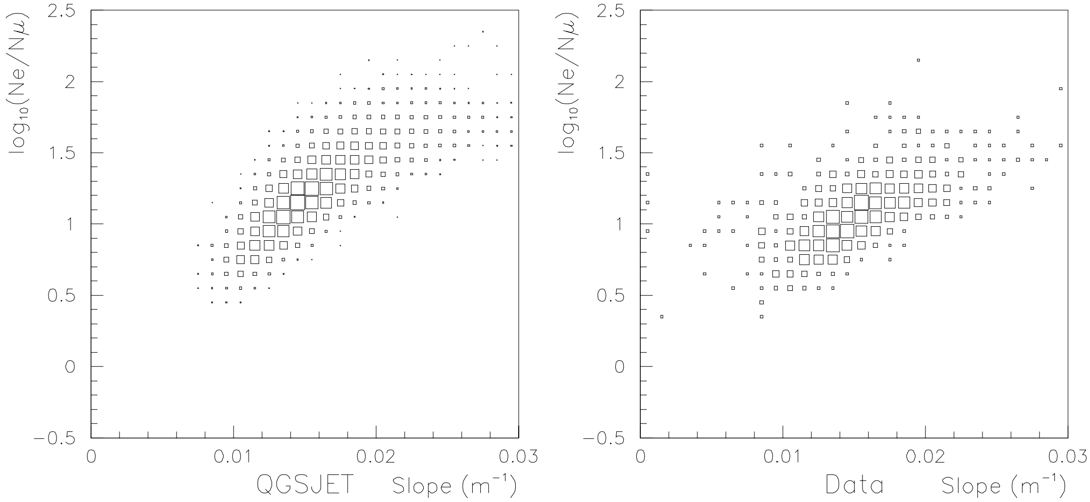

Figure 2: Correlation of CASA and BLANCA composition parameters in simulated and real data.

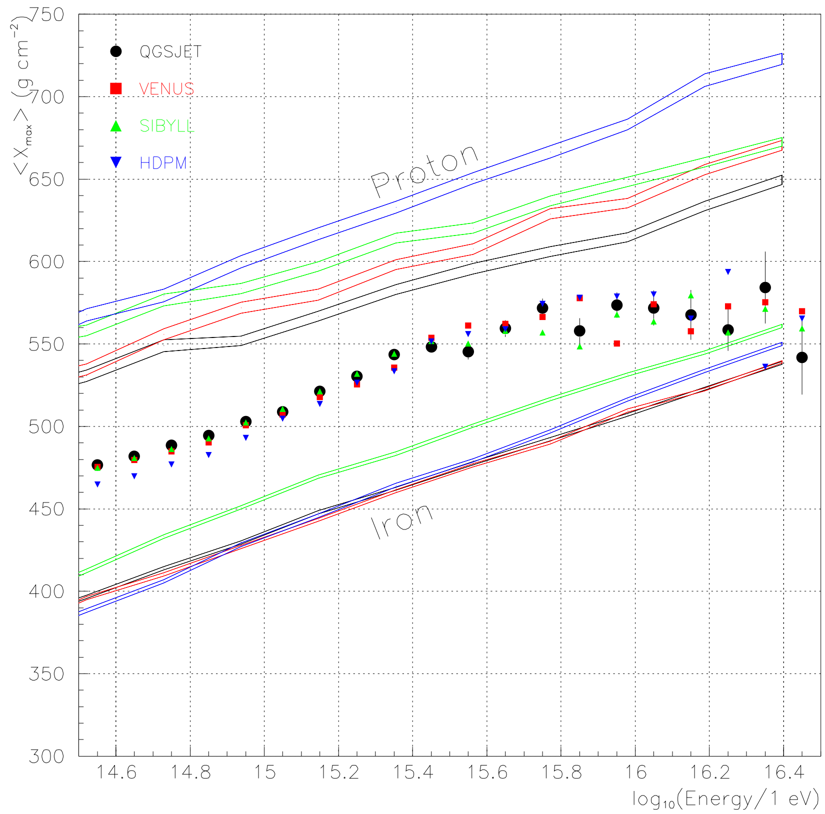

Figure 3: Preliminary BLANCA mean X_{max} result extracted using several interaction models.

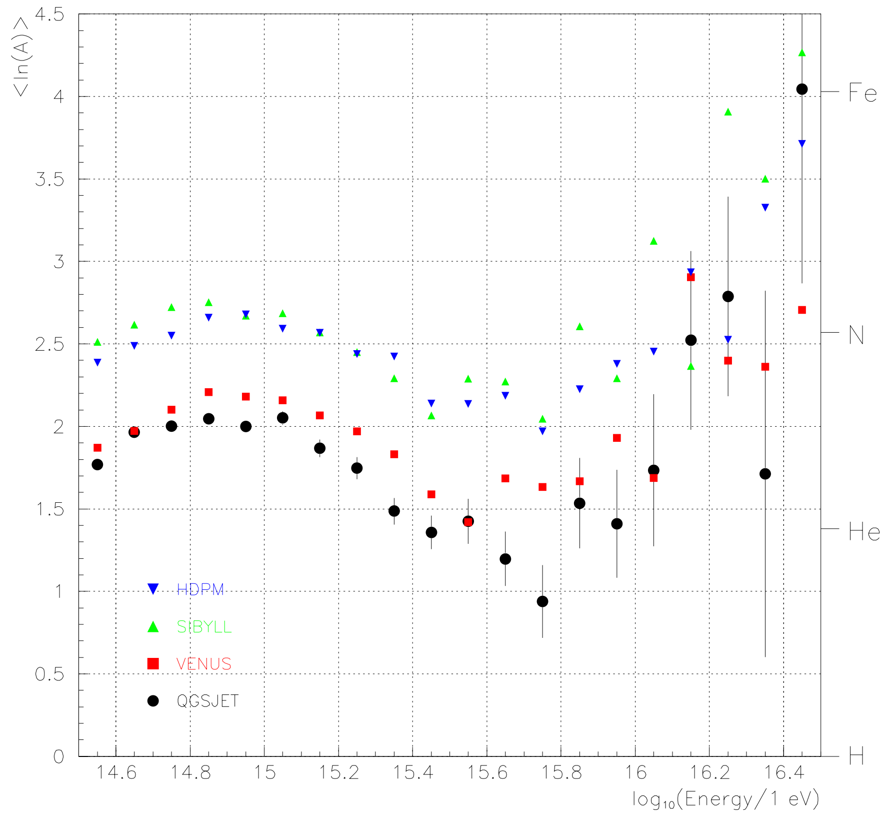

Figure 4: Preliminary BLANCA mean primary mass result extracted using several interaction models.

primary mass decreases through the knee, then appears to rise above 5 PeV.

4 Conclusions

The CASA-BLANCA Cherenkov array has observed cosmic ray air showers above 300 TeV with an exposure of 10^{10} m$^2\cdot$ sr$\cdot$ s. The energy spectrum has a smooth knee around 3 PeV, with the spectral index increasing from -2.7 to -3.1. The mean depth of shower maximum has been presented and compared to four interaction models. Finally the mean primary mass has been extracted. All models show the same trend; that the mean primary mass decreases across the knee and then starts to rise. A more sophisticated analysis is underway which extracts the fraction of different nuclear groups versus energy — results will be presented at the conference.

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