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Nottingham-MSU INTAS Mass Composition Project

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Abstract

The Nottingham muon experiment at Haverah Park and the Moscow State University (MSU) array / muon detector give conflicting results for the mass composition of the PCR around and above the knee of the energy spectrum. Whilst the Nottingham data indicate a decrease in the mean mass in the decade below the knee, followed by an essentially unchanging composition above, the MSU group report an increase in <A>, in accord with the contemporary diffusion model.

This paper outlines an attempt to reconcile the differences between the two results by Monte Carlo simulation of EAS data for both detector arrangements using the CORSIKA code.

1 Introduction:

The mass composition around the knee (at $E_{pr} \sim 3*10^{15}$ eV) is of great importance as a test of models of acceleration and propagation of cosmic rays. The determination of the composition above 10^{14} eV, however, is greatly hampered by the absence of direct data, due to the low flux and high energies of such particles. For this reason composition must be inferred from the properties of EAS detected by earthbound arrays. Interpretation of the data is made problematic by their dependence on the details of hadronic interactions – specifically production in the far-forward region - which may not be ascertained in current accelerator experiments.

According to simulations, the muon component of an EAS offers several mass-dependent properties, which have all been utilized at one time or another. In the Nottingham experiment, the ratio of the muon density to a neighbouring Cerenkov detector's 'all-particle' density, ρ_μ / ρ_c at a given core distance was used [see Blake and Nash (1995a, 1995b, 1998)]. It is expected that $\rho_\mu \propto \rho_c^\alpha$, with α slightly less than 1 for the muon energy threshold of the experiment ~320 MeV at energies below the knee. For a given composition, α would be expected to have only a slow dependence on primary energy. A sharp decrease in this value in the decade below the knee was taken to signal a decrease in <A> over this range.

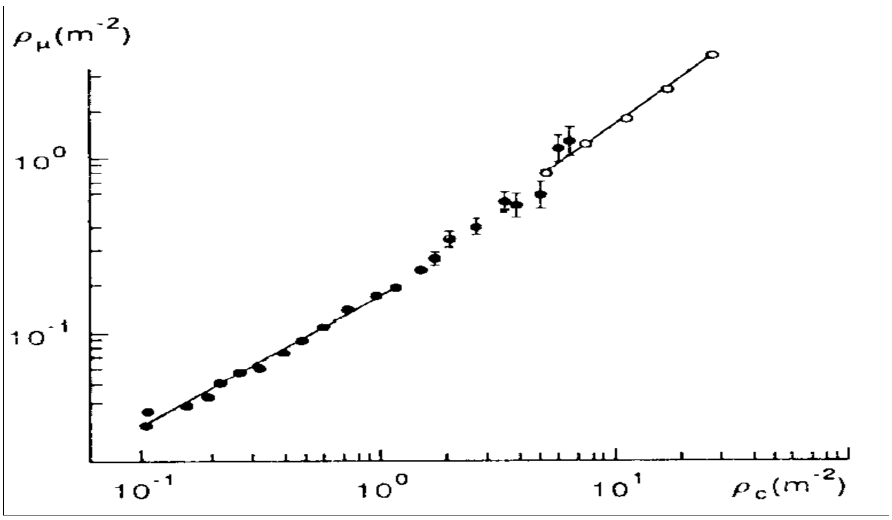

Figure 1 - <ρ_μ> vs. <ρ_c> for sec θ < 1.1 E_{pr} range is ~ $4*10^{14}$ - ~ 10^{17} eV. Filled circles are GREX data, open circles are from the earlier 150m array. After P.R. Blake and W.F Nash (1995b)

At the MSU experiment [described in Vernov *et al* (1979)] the muon energy threshold was 10 GeV and the level of fluctuations of the muon content as well as the relationship between the 2-d muon distribution and electron LDF gradient were considered [see Fomin (1996, 1997), Fomin *et al* (1998)]. Experimental data were compared with simulations using the QGSJET version of CORSIKA. The best fits for energies below and above the knee are given in the table below [after Fomin *et al* (1998)]:

ΔlnN_e	*5.0 – 5.6 (below knee)*	*7.0-7.6 (after knee)*
(p+α)	62±5	24±5
(H+VH)	19±5	63±7

It is clear that at least one of the obtained compositions must be incorrect, but that is not to say that the two datasets must be inconsistent if one or more of the measured properties are less reliable mass indicators than supposed.

2 Simulations using CORSIKA and GEANT:

During phase 1 of this project, the QGSJET version of the CORSIKA code will simulate showers reaching the observation levels of the two experiments. Using GEANT to give the detector responses for each shower and for each experiment, it may be possible to obtain a satisfactory fit to the observations.

The mooted phase 2 would involve stitching a newer hadronic interaction model, possibly based on a cut-down version of one of the CERN models. Though none of the five models currently stitched into CORSIKA differ enough in the region of interest to be excluded (no more than 50% in any property for protons, with the Gribov-Regge models giving even closer results [J. Knapp, D. Heck and G. Schatz, (1997)]), the differences suffice to throw doubt onto mass composition estimates based on them. It may, then, be considered advantageous to use 'the best model we have' [T. Sloan (1999)]. Time is, sadly, virtually certain to preclude the completion of that task.

2.1 Code Optimization and Parallelisation

Level Three access to the 40-processor SGI Origin 2000 at Manchester Computing Centre has been sought and obtained. Total allocated processor time being limited, the author is seeking to achieve the maximum practicable speed-up. Courses have been attended and profiling of the code with the required CORSIKA options is taking place. Parallelisation will probably be left to the high-quality SGI compiler, making use of the '-pfa' flag or minimal OpenMP directives; the clock time taken being of less importance than processor time.

As a validation check, a short run on the Origin2000 will be compared with those of a pre-compiled binary on the 4 * 300 MHz Alpha machine at the University of Nottingham. As the QGSJET interaction model will be selected at the pre-compilation stage, another level of validation will be possible by direct comparison with the simulated data of the MSU group.

2.2 GEANT Detector Simulation

The full GEANT description of the detector arrangement at Haverah Park has been completed, but that of the MSU remains undone at time of writing. When both are complete, they will be used to extract the salient data from the output of CORSIKA at the respective observation depths of the two experiments.

3 Scope of Expected Results:

As referred to in the introduction, the dependence of the results on hadronic interaction model as well as mass composition rules out a definitive answer on either score until the other is known. Therefore the purpose of this project is merely to emphasize – or otherwise – the reliability of the reported results.

In the medium term the LHC should be able to give considerably better knowledge of hadronic interactions, not only at higher energies, but also in much further-forward regions. At that point will it be possible to infer more about the mass composition.

4 Conclusion:

The importance of the mass composition to CR physics is the only thing about it that is not in doubt. As a result of the length of time over which data have been collected, results must occasionally be re-evaluated in the light of newer and ever more sophisticated models and experiments. That is all that can be done, but the results are potentially interesting whether agreement is reached or not.

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