May 25, 1999

Studying Extended Air Showers with CosmoAleph

Michael Schmelling / MPI für Kernphysik

for the CosmoAleph-Group

C. Grupen[9], J. Kempa[7], S. Luitz[3], M. Maggi[1], D. Maier[9,10], A.-S. Müller[3,8], A. Putzer[5], B. Rensch[2], H.-G. Sander[8], S. Schmeling[8], M. Schmelling[6], V. Schreiber[9,4], H. Wachsmuth[3,8], T. Ziegler[8]

[1]Dipartimento di Fisica, INFN Sezione di Bari, I-70126 Bari, Italy.

[2]now at Niels Bohr Institute, DK-2100 Copenhagen, Denmark.

[3]CERN, CH-1211 Geneva 23, Switzerland.

[4]now at Partner Consult GmbH, Hamburg, Germany.

[5]Institut für Hochenergiephysik, Universität Heidelberg, D-69120 Heidelberg, Germany.

[6]now at MPI für Kernphysik, D-69029 Heidelberg, Germany.

[7]Cosmic Ray Lab., Inst. for Nucl. Studies, Pl-90950 Lodz, Poland.

[8]Institut für Physik, Universität Mainz, D-55099 Mainz, Germany.

[9]Fachbereich Physik, Universität Siegen, D-57068 Siegen, Germany.

[10]now at Toto-Lotto GmbH, Stuttgart, Germany.

1 Introduction

The CosmoAleph-project was initialized by Horst Wachsmuth as a pilot experiment for CosmoLEP [1] in order to explore the feasibility of using the existing LEP-infrastructure to search for coincidences between distant detector stations. Since the observation of coincidences between different LEP detectors is extremely unlikely for conventional EAS [2], such a measurement would be strong evidence for correlations between distinct air showers, confirming experimental indications [3] for correlations between independent detectors observed over distances as large as a few 100 km. CosmoAleph focuses on the study of the muon component of extensive air showers at an intermediate cutoff energy around 70 GeV, which already makes it sensitive to the high energy component of primary cosmic rays.

2 Experimental Setup

The experimental setup of CosmoAleph covers the barrel part of the ALEPH hadron calorimeter ("HCAL") plus a few scintillator stations in the ALEPH cavern, in a bypass-tunnel of LEP around the experimental hall and one distant station in an electronics alcove of the LEP tunnel. Each of those stations consists of several stacks of two scintillators which are read out by photomultipliers at both ends. A schematic layout is shown in fig.(1). The whole array spans distances between 18 m and 1150 m, with currently an integrated uptime between 100 and 173 days for different pairings. All detectors have an independent DAQ system. A scintillator station is read out when at least one stack has a coincidence between both layers, the HCAL trigger requires a penetrating track through the barrel detector. The timing information stored for each event consists of the LEP BST-signal, which is synchronized to one revolution of the beam in LEP, a fast 80 MHz clock interpolating the BST and the system time of the readout processor. The BST count is reset every 2^{15} turns, i.e. roughly every 3 seconds. Since 1998 also GPS-time is read out, allowing to derive a calibrated global time stamp for each event. Coincidences between stations are determined off-line by using the system time to determine for each event the reset cycle since start of run. Details of the setup, trigger scheme and analysis are described e.g. in [4].

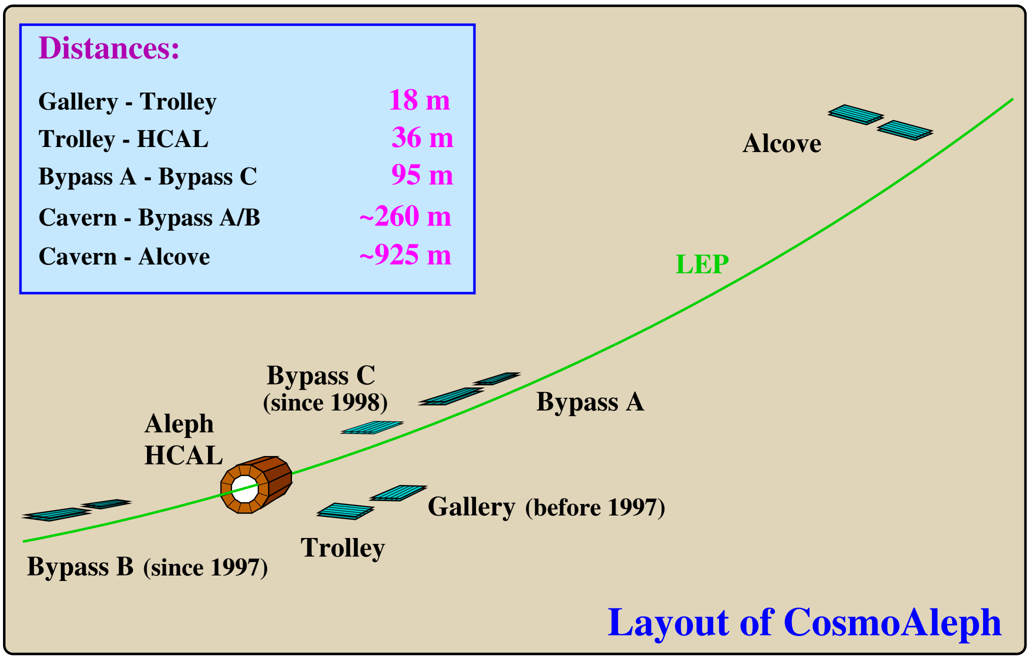

Figure 1: *Layout of the* COSMOALEPH*-experiment*

3 Results

Coincidences were observed between stations as far apart as 500 m. The normalized rates, coincidences per day and m^4 as function of the distance is shown in fig.(2). It represents the number of coincidences observed per day between two 1 m^2 detectors, integrated over all primary energies and angles. Starting with a roughly exponential behaviour the curve surprisingly flattens at distances above 400 m.

4 Monte Carlo Simulations

An important question is whether the measured coincidence rates are consistent with the expectation from the known properties of extensive air showers. Ideally a full simulation of the

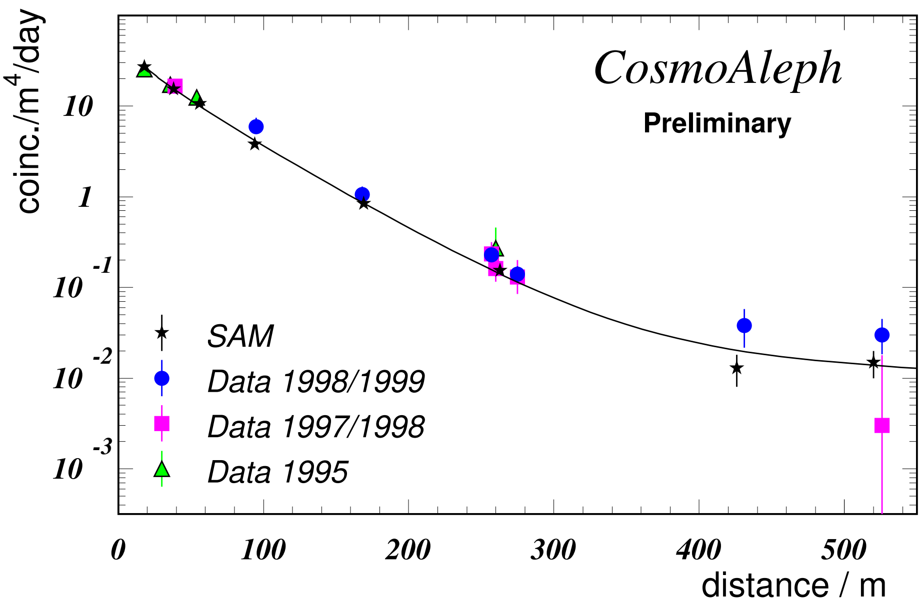

Figure 2: *Measured coincidence rates between two unit-detectors as function of the distance. Also shown is the prediction from a Monte Carlo simulation ("SAM") obtained after the workshop. The curve is a phenomenological fit to the Monte Carlo results.*

experiment e.g. with the CORSIKA [5] shower program should be performed. Unfortunately this is not feasible with the available computing resources. Therefore a different approach was adopted, parameterizing the properties of the EAS muon component as predicted by CORSIKA [6] for the CosmoAleph depth of 320 mwe in a similar way as described in [7]. Based on this modified parameterization a fast simulation was performed. The ingredients are an isotropic primary flux of nuclei with a fixed standard 5-component chemical composition [8], muon multiplicities generated according to a negative binomial distribution with mean value and lateral distribution adjusted to CORSIKA and width taken from [7]. Details of the simulation and the user interface will be described in a forthcoming paper [9].

The fast simulation of the muon component neglects kinematic correlation between individual shower particles. However, since the detector areas are small compared to the full extension of the shower, such correlations can be expected to have only negligible impact on the predicted coincidence rates. Being fast, the experiment can be simulated for the full integrated uptime. No weighting factors are needed and the impact of rare events from the tails of the distribution is taken properly into account. The latter aspect is quite important because of the steep energy spectrum of the cosmic ray primaries. The flux of 1 TeV primaries is roughly 100 million times larger than at 1 PeV, i.e. rare events which occur at the level of 10^{-8} at 1 TeV can have the same impact on the results as 1 PeV particles, and most likely would go completely unnoticed when weighting a Monte Carlo prediction from a small sample of 10^5 low energy showers by 10^3.

Figure (3) shows the sensitivity of the CosmoAleph coincidence rate to the primary energy spectrum. The convolution of a steeply falling spectrum with a rising coincidence probability leads to a maximum sensitivity just below the knee in the primary spectrum. The new curve in fig.(3), like the Monte Carlo prediction for the relation between coincidence rate and distance,

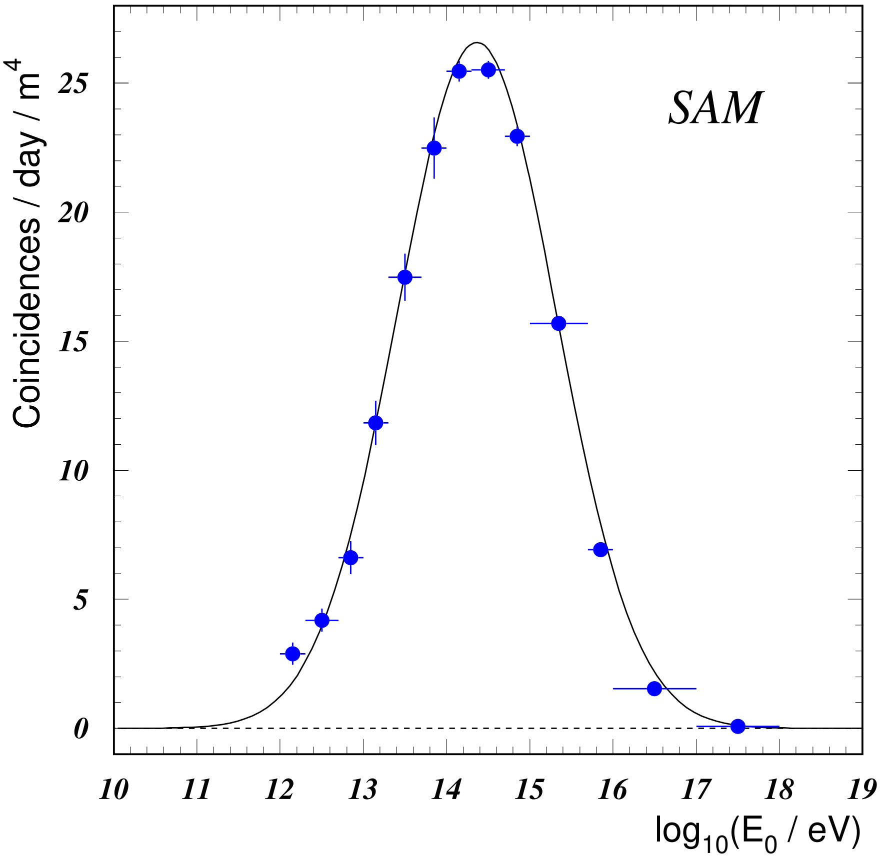

Figure 3: *Sensitivity of the* CosmoAleph *experiment to the primary cosmic ray energy. The plot shows how the total coincidence rate* n_c *varies with the logarithm of the primary energy* $dn_c/d\lg E$*. The curve is a gaussian fit to the Monte Carlo results.*

was obtained after the workshop and superseedes the similar result given in [4]. Varying the experimental conditions, the maximum sensitivity of a coincidence measurement can be shifted to lower energies by going to more shallow depths or smaller distances. On the other hand, larger depths or increased distances will be more sensitive to the high energy component.

In [4] it has been shown, that the coincidence rate as function of distance as well as coincidence rates between more than two detectors is sensitive to the atomic number of the cosmic ray primaries. Using the shower model from the parameterization of CORSIKA thus also allows to give constraints on the chemical composition of the cosmic ray flux in the region of the knee.

5 Summary and Outlook

This paper describes the coincidence rates measured with the CosmoAleph experiment at CERN. It demonstrates the potential for directly probing the muon lateral distribution of extensive air showers up to distances of several hundred meters from the shower core for an overburden of 320 mwe. The good agreement between data and simulation indicates that also information about the chemical composition of the primaries can be obtained. Other types of studies not covered here are measurements of the correlation between muon flux and atmospheric pressure, limits on the day-night variations or the search of point sources with the barrel of the ALEPH hadron calorimeter. These topics are presented in [10, 11]. For more detailed information see also [4, 12] and [13].

Acknowledgments

The ALEPH-collaboration is gratefully acknowledged for its support of the CosmoAleph project. Special thanks go to A. Pacheco, M. Frank, B. Jost for their assistance integrating CosmoAleph into the ALEPH data acquisition system and in particular A. Bechini for technical support.

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