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CosmoLEP, an underground cosmic ray muon experiment in the LEP ring

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Abstract

The CosmoLEP collaboration proposes to investigate cosmic muons using the ALEPH experiment complemented by additional instrumentation. Preliminary analyses of cosmic multi-muon events taken by the ALEPH experiment alone indicate that the rate of the spectacular highest multiplicity muon events is in excess of that predicted by standard Monte-Carlo simulations. In order to obtain essential additional information about the size, structure and radial profile of the showers, CosmoLEP will augment the ALEPH detector by installing 200 m^2 of muon chambers in the ALEPH underground cavern, beginning some 20 m from the ALEPH detector. Together with additional chambers and counters further away in the LEP tunnel, CosmoLEP will be a powerful tool for studying cosmic ray air showers in the energy range of $10^{15} - 10^{17}$ eV. Studies of multi-muon bundles and coincidences (including coincidences with other LEP detectors) will enable significant progress in understanding the composition of cosmic ray primaries in the vicinity of the "knee", as well as provide important information about multiparticle production in previously unexplored regions of phase space.

Contents

1 Physics Goals and Overview of CosmoLEP

Studies of high multiplicity cosmic muon events, called muon bundles, can provide significant information about both particle production in previously unexplored kinematic regions and about the composition of primary cosmic rays at energies where this is still quite uncertain. Unprecedented data can be obtained by using existing LEP detectors together with additional arrays of muon chambers and counters within the LEP tunnel and experimental caverns. The importance of this data follows from the fact that multi-muon bundles have never been studied with such precise detectors, nor have they been studied at this depth.

The CosmoLEP collaboration proposes to extend the ALEPH detector with additional muon chambers and counters in the experimental cavern. Additional instrumentation, in the form of muon chambers and scintillation counters, may also be placed between ALEPH and L3. Coincidences with other LEP experiments and experiments located elsewhere will also be studied. The use of large underground detectors at CERN for cosmic ray studies has been previously suggested by several groups, e.g. UA1 [1] and the LEP experiments [2]. The underground location of the LEP detectors, between 30 and 140 meters, is ideal for muon based measurements: the electromagnetic and hadronic components of the air showers of cosmic rays are fully absorbed by the layer of earth, and the muon momentum cut-off is between 15 and 70 GeV, depending on the depth.

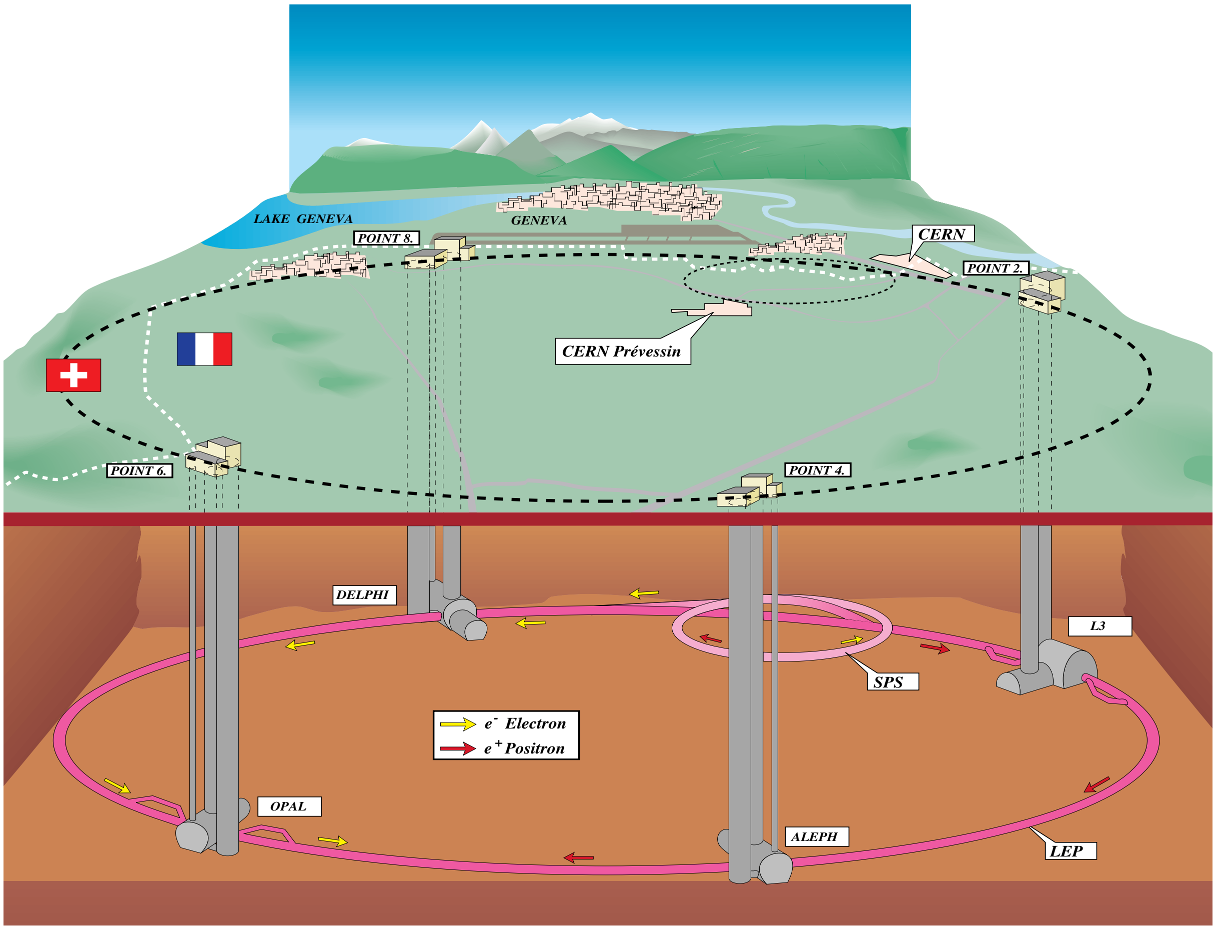

Figure 1.1. *Sketch of the LEP ring and the four experiments, located underground at a depth of 30–140 m*

This is in contrast to deep underground experiments, such as MACRO [10] and Frejus [19, 20] where the momentum cut-off is of order of one TeV, as well as to surface experiments, such as KASCADE [4], where the cut-off is of the order of GeV. Cosmic ray experiments using the LEP infrastructure are clearly complementary to previous and existing cosmic ray muon experiments which are either much deeper underground or located on or very near the surface.

The use of large underground high energy physics experiments for cosmic ray studies offers, for the first time, the opportunity to have large area magnetic analysis which will provide the precise determination of the direction of cosmic ray muons as well as their momentum up to order of one TeV. The fine granularity of the detectors also permits the identification, measurement and study of a large number of muon tracks within a small area, so called muon bundles. In addition, calorimetric measurements can be used to tag very high energy muons which undergo catastrophic energy loss. The total underground area potentially available for CosmoLEP is shown in Fig.1.1, including the four existing LEP experiments.

The original idea of CosmoLEP [2] was to measure coincidences between the four LEP experiments. Large distance correlations would not be expected from "standard" extended air showers. Events spreading over two or more LEP detectors would therefore be indicative of extra-atmospheric radiation created in spectacular interactions. To allow these measurements the four LEP experiments should have a 100% duty cycle trigger. At the time of that early proposal in 1993 only ALEPH could provide a cosmic trigger independent of the LEP beam crossing signal. Members from the ALEPH collaboration started a pilot experiment (CosmoALEPH) by adding counter arrays around ALEPH over a distance of up to 1 km (see Section 5). Since then, the L3 experiment has established a cosmic ray experiment branch of its detector (called L3C) [3] which takes data in parallel with the normal L3 readout, and has as a principal aim the measurement of the muon spectrum in cosmic rays. The other LEP experiments (DELPHI and OPAL) are also interested in cosmic ray physics and are analysing their special cosmic ray runs.

The utility of LEP experiments based data for cosmic ray studies has already been explored in preliminary analyses of multi-muon events recorded by the LEP experiments, using triggers during the normal e^+e^- data taking of the experiment. The analysis of the ALEPH data is discussed in section 2. The results indicate that the rate of the spectacular highest multiplicity muon events is in excess of the rate predicted by standard Monte-Carlo simulations.

We propose to augment the ALEPH detector by installing 200 m^2 of muon chambers in the ALEPH experimental hall beginning some 20 m from the detector. These chambers will provide additional information on the size, structure and radial profile of the muon bundles, and will permit the further study of this intriguing high multiplicity excess by collecting much larger data sets, thus dramatically improving the statistics.

1.1 The cosmic ray spectrum

A primary cosmic ray nucleon will, on average, have its first interaction with an air nucleus at about 20 km above the earth's surface. The muons originate from hadronic cascades started by the interaction of cosmic ray particles in the atmosphere. The primary cosmic ray flux, as measured by a variety of experiments in recent decades, is shown in Fig. 1.2 [5]. At the lowest energies, where the rates are high, the most precise measurements have been made with balloon experiments with small detectors. These experiments can observe directly the primary interaction, and study the particle composition from primary cosmic rays. As a result, the spectrum of cosmic rays at the top of the atmosphere has been well established over many orders of magnitude in the lower part of the energy range.

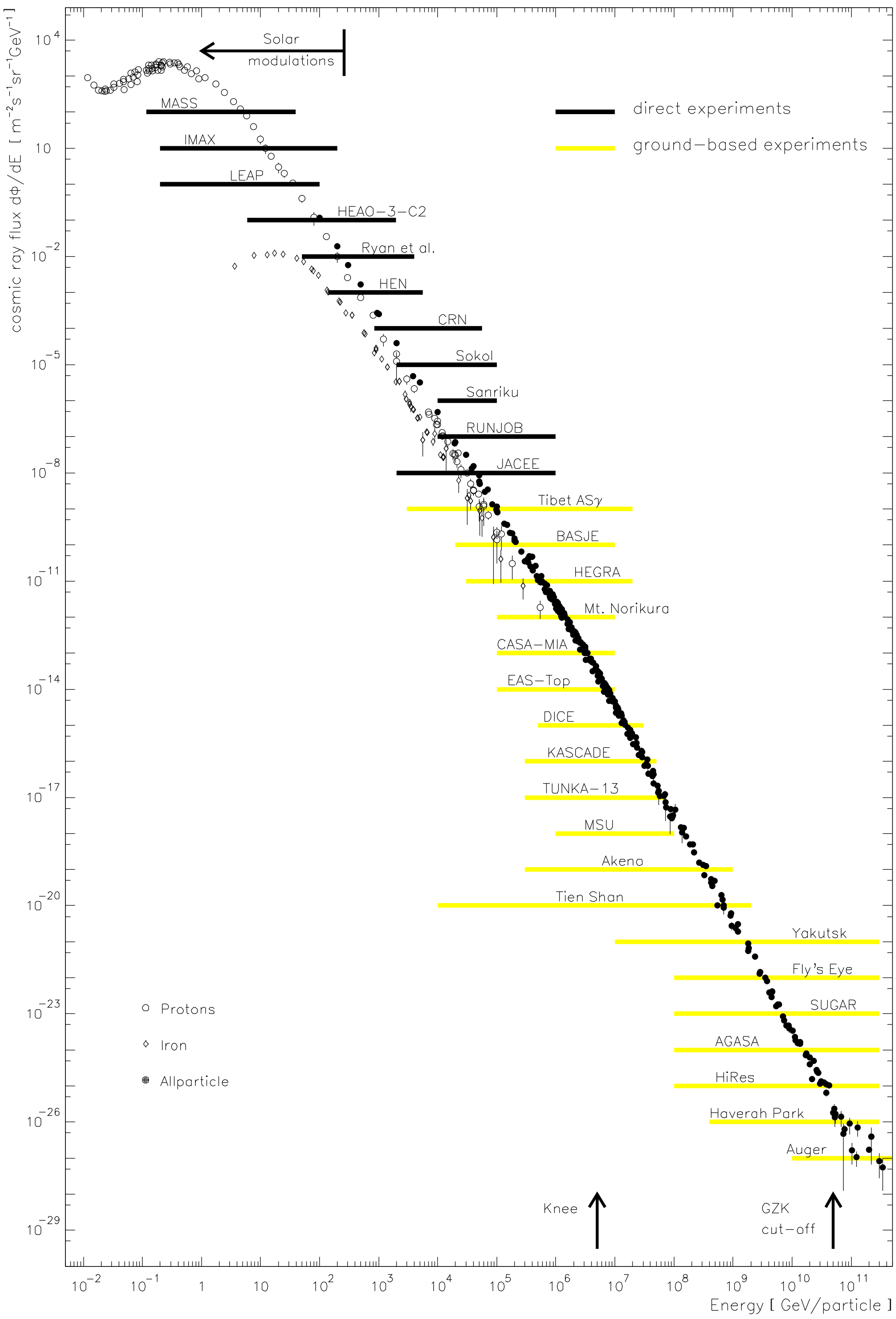

Figure 1.2. *Energy spectrum of primary cosmic rays with the energy ranges of the experiments (taken from [5], where the indicated experiments are also referenced).*

For energies above 10^{15} eV the event rate becomes too small for balloon experiments and ground based large area detectors are needed to study cosmic rays at high energies. Interestingly, around that energy, namely between 10^{15} and 10^{16} eV, a very prominent and well known feature of the cosmic ray spectrum becomes visible: a steepening which is known as the "knee" of the spectrum. Cosmic rays in this energy range are thought to be of galactic origin, and hence the knee presumably represents some, but not all, cosmic accelerators reaching their maximum energy.

While the energy spectrum is well established, the composition of cosmic rays above energies of about 10^{14} eV is still unsolved and the subject of much active research. The present data on the particle composition of cosmic rays as function of the incident energy is shown in Fig.1.3 [6]. It shows that at energies well below the knee the particles are dominantly protons. Around the knee there seems to be a transition to heavier nuclei but the data covers a wide range and is not yet conclusive. Precise measurements are given by the recent data of the KASCADE experiment in Karlsruhe, which consists of a large surface area of 200 x 200 m^2 of detectors for the electromagnetic shower and muons. One of the basic difficulties of these detectors in the reconstruction of the primary energy and mass is the fluctuation in the shower development in the atmosphere and in particular the modelling of the forward particle production in the cascade.

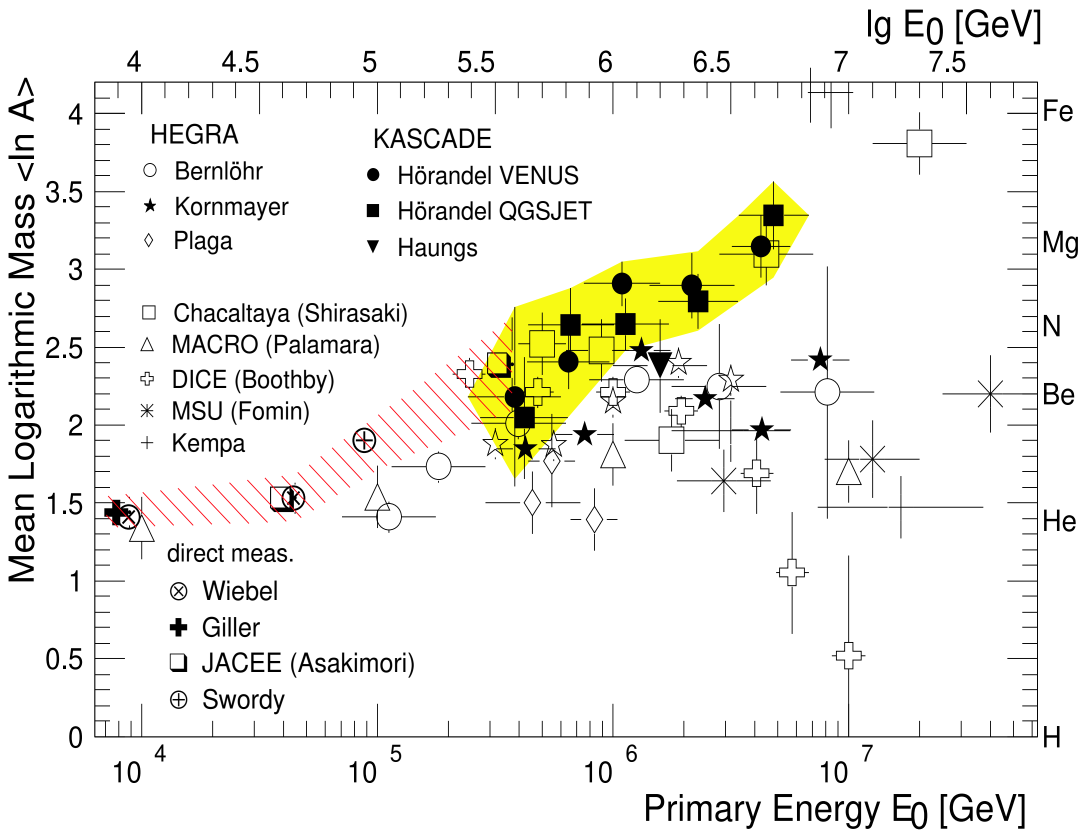

Figure 1.3. *Chemical composition of primary cosmic rays (from [6]).*

1.2 Muon production in cosmic air showers

In the vicinity of the knee, the primary collision of the cosmic ray with the nuclei in the atmosphere corresponds to a center of mass energy above that probed in $p - \bar{p}$ collisions at the Tevatron. Even at Tevatron energies, many aspects of particle production are completely unknown: almost nothing is known about forward production, and even less is known about production of particles with less than a generic p_t of a few hundred MeV. One cannot extrapolate from what is known from lower energies. There are ample reasons to expect surprises in this totally unexplored energy regime. These uncertainties are even larger in the case of nucleon-nucleus collisions, and nucleus-nucleus collisions.

One possible indication of such surprises has been provided by the JACEE collaboration, using a balloon-born emulsion experiment designed to probe the primary cosmic ray composition. They have reported several events exhibiting "centauro" and "anti-centauro" behaviour, an anomalously large number of photons or charged particles in a limited "pseudorapidity-azimuth" phase space, possibly indicative of "Disoriented Chiral Condensate" (DCC)-like low-p_t production [7]. One such event is illustrated in Fig. 1.4 [8].

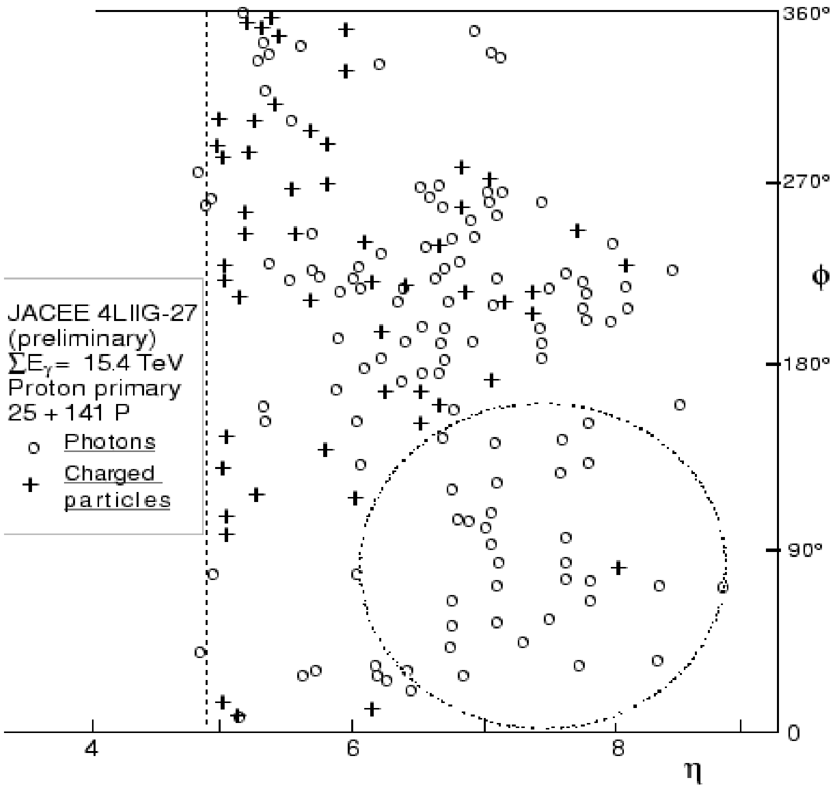

Figure 1.4. *Example of a high multiplicity event with an anomalous concentration of photons in a limited range of phase space [8].*

The situation is further complicated because the first interaction occurs many interaction lengths above the surface of the earth. As a result, some observable quantities are almost calorimetric in nature, and only modestly sensitive to the many uncertainties. This has been important in establishing the energy spectrum. In order to efficiently trace back the details of shower development and to probe details of the primary cosmic ray composition or the forward production process, the maximum set of observables should be used. The multi-muon bundles, detected with an experiment under a suitable overburden, are complementary to the usual techniques of cosmic air shower measurements.

Muons, because they originate from the decay of hadrons, and do not multiply but only slowly lose energy by ionization as they traverse the atmosphere, are particularly useful in this regard. Further, muons of different energies provide somewhat different tracers of shower development. Pions with energy around 100 GeV decay to muons with energies comparable to the cut-off at the ALEPH experiment. At this characteristic energy pions have a similar probability to interact or to decay in the upper atmosphere. Thus, studies of very high energy muons in experiments deep underground probe different aspects of the shower than do the very low energy muons studied by surface experiments. A unique feature of CosmoLEP is that it operates in the vicinity of this characteristic energy: surface experiments have cutoffs much smaller than this energy, and deep underground experiments have cutoffs much larger than this energy.

Another important aspect of muons from cosmic ray air showers is the transverse size of the bundles. Fig. 1.5 illustrates the radial muon distributions produced by proton and iron induced air showers for three different energies ranges relevant to CosmoLEP, as predicted by CORSIKA simulations. It is clear that the proposed CosmoLEP design is well matched to these profiles: for events in which the ALEPH detector is triggered by a muon bundle, the curves for proton and iron differ by more than a factor of two at the location of the muon chamber array.

The ability to actually measure the energy of muons using the ALEPH detector will be a powerful tool for disentangling the various uncertainties inherent in modelling shower development. Observing the spatial extent and density of the shower by using the muon array together with the ALEPH experiment, will provide the information needed to reconstruct the primary cosmic ray energy and composition. CosmoLEP will thus be highly efficient in investigating cosmic ray air showers, particularly in the energy range $10^{15} - 10^{17}$ eV.

1.3 Underground muon experiments

Cosmic muon measurements which began around 1937 are being continued by modern underground experiments, some of which were originally designed for proton lifetime experiments. The cosmic muon flux is steeply decreasing with the amount of overburden, expressed in km water equivalent (w.e.) or hg cm^{-2} (Fig. 1.6). The underground locations of the most important experiments are indicated in the same Figure, together with the overburden range in which they measure the muons. Except for the underwater experiments which have rather crude spatial resolution, most of the experiments are placed deeply underground with a typical momentum cut-off of one TeV or larger. These experiments study the topological properties of multi-muon events, such as decoherence, for large momentum muons. Due to the low rate, these detectors are large and hence their granularity is poor. Other experiments closer to the surface have calorimetric detectors only, without precise tracking. In this context, CosmoLEP with its location at about 300 m w.e. and the well known geological composition of the overburden rock will give unprecedented new data about the cosmic shower muon component. The size of the detector area, the spatial resolution and the pattern recognition in complicated high-density events play a decisive role in the multi-muon studies. An additional virtue of CosmoLEP is the near-by location of the Jura mountains: by choosing an appropriate angle below 20 degree, the overburden can be increased to more than 10 km w.e. This permits simultaneous measurements at very different overburdens.

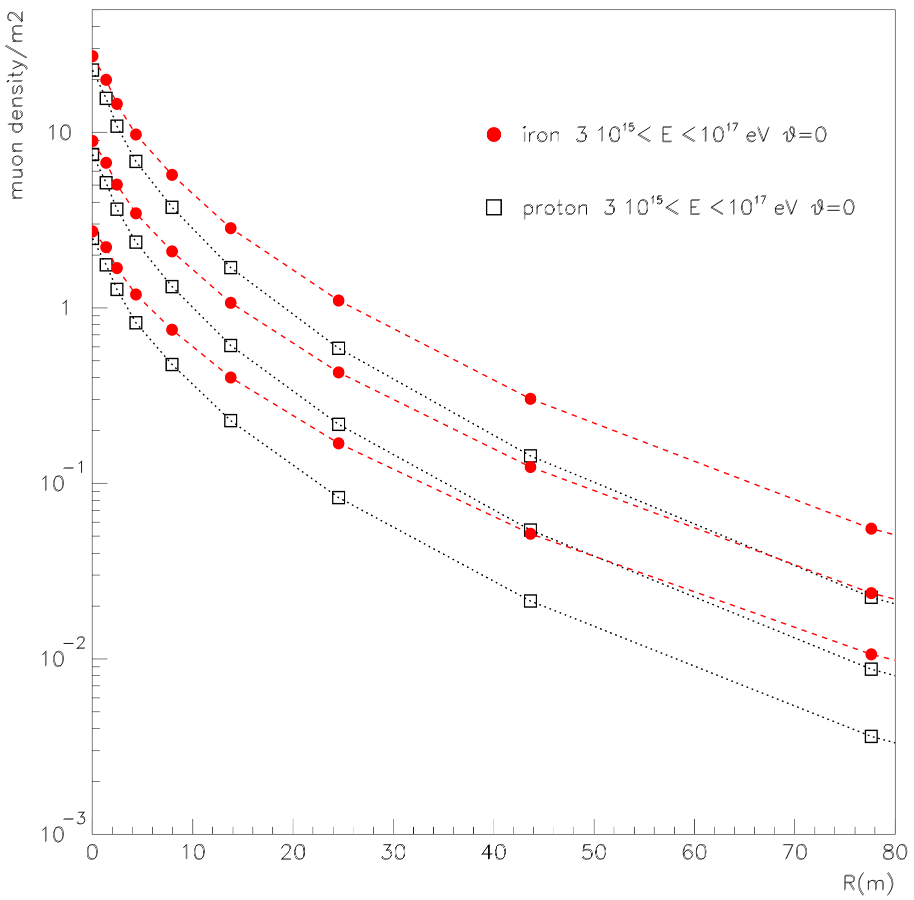

Figure 1.5. *Muon lateral distributions for vertical iron and proton induced showers. The primary energy ranges are: E=*$3 \cdot 10^{15} - 10^{16}$*;* $10^{16} - 3 \cdot 10^{16}$*;* $3 \cdot 10^{16} - 10^{17}$ *eV.*

1.4 Muon Astronomy

While the most important point of CosmoLEP is to investigate multi-muon bundles, the CosmoLEP experiment can also be used as a telescope to look for point sources in our galaxy and possibly beyond [21]. Charged primaries in the relevant energy regime cannot be used for astronomy because irregular galactic magnetic fields obliterate their original direction of emission. For charged primaries this problem is only overcome at sufficiently high energies ($> 10^{19}$ eV) where the particles travel essentially along straight lines from the source to the Earth [22]. But here, the collection rate of CosmoLEP is too small to be useful.

Consequently, muon astronomy can only be performed with neutral primaries, such as photons, neutrinos, neutrons or exotic particles (SUSY particles, dust grains, ...). Such neutral parent particles, which carry the directional information, undergo an interaction in the atmosphere producing muons which are then detected by CosmoLEP. The photons with energies in excess of 300 TeV are absorbed by blackbody microwave photons, thus reducing their mean free path to 10 kpc. For photons with energies above 10^5 TeV the cosmos becomes again more transparent (see Fig. 1.7).

Neutrinos are in principle very promising candidates. However, their interaction probability in the atmosphere is rather low and the background from atmospheric cosmic rays is large, so that one would have to rely on upward going muons only.

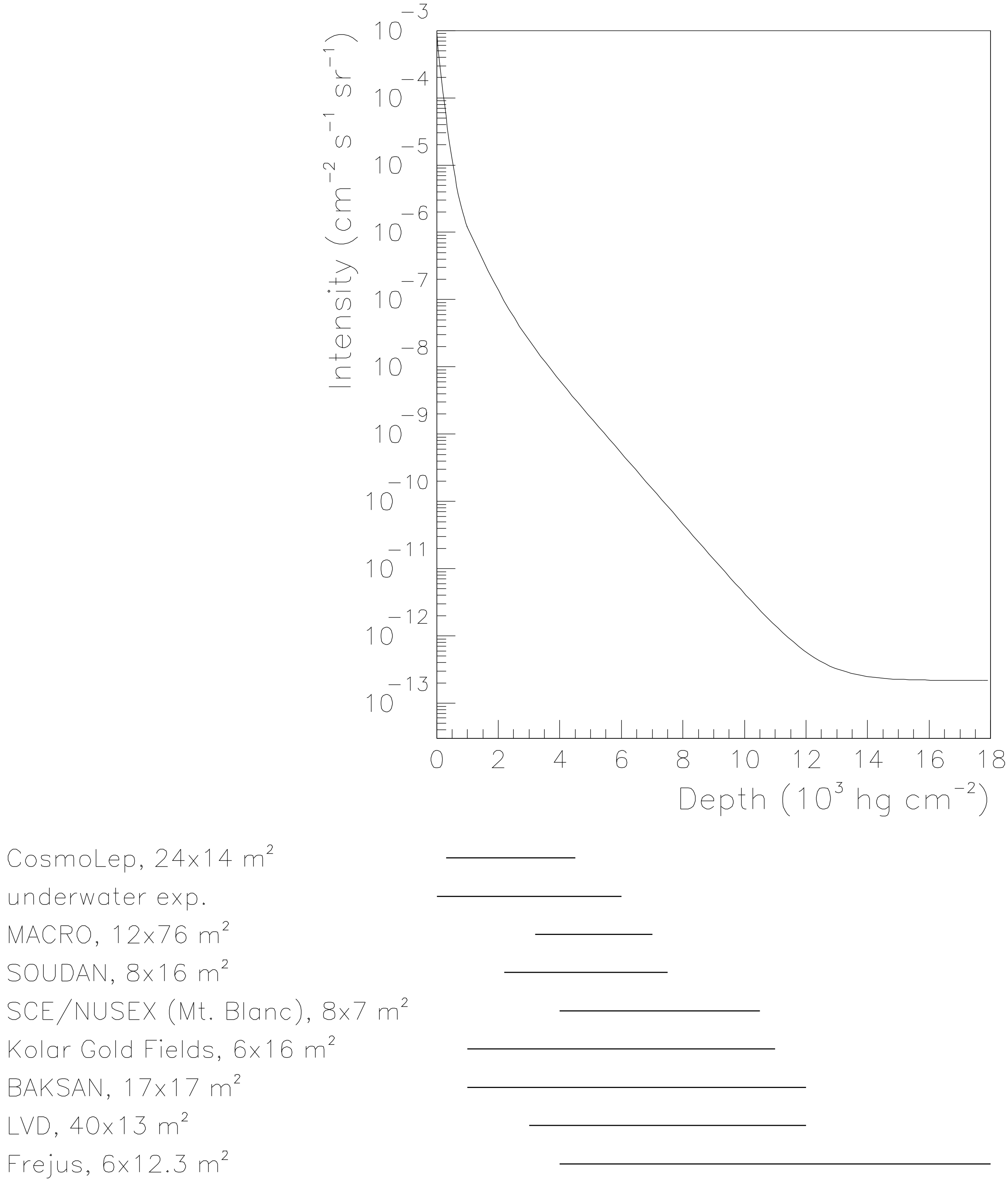

Figure 1.6. *The muon flux as a function of depth as measured by underground experiments [9]. The depth ranges of some experiments are also drawn. References: underwater experiments – see [9]; MACRO – [10]; SOUDAN – [11, 12]; SCE – [13]; NUSEX – [14]; Kolar gold fields – [15]; BAKSAN – [16, 17]; LVD – [18]; Fréjus – [19, 20]*

As far as neutrons are concerned there must be many around from cosmic sources. Because of their decay properties, the abundant cosmic neutron can only be used for astronomy if they come from the immediate vicinity (10 to 100 pc at 1 to 10 PeV). Whether there are cosmic ray sources that near to us may still seem questionable. Neutrons provide a chance to scan the whole milky way via their strong interactions, only one has to look for substantially higher energies of the order of one EeV to penetrate deeper into the galaxy.

Exotic particles (like WIMPs) are likely to be somewhere, but their interaction cross-sections are small and the chance to find them with CosmoLEP is rather small. Energetic dust grains are also not too promising, because one would assume that originally they must have been charged (otherwise there is no chance to accelerate them), and thereby subject to magnetic deflection. Only neutral fragments of originally charged energetic dust grains are possible candidates. These arguments suggest that the most promising candidates for muon production are photons.

There are known sources of energetic gamma-rays in our galaxy and also at extragalactic distances. Experiments using the atmospheric Cherenkov technique have confirmed that sources long-known or those discovered by the Compton Gamma Ray Observatory (CGRO) in the GeV-range extend into the TeV-range and even beyond [23]. The most promising sources are the Crab nebula, the pulsar PSR 1706-44, and the active galaxy Markarian 421. The gamma-ray spectrum of the Crab nebula is, for example, known to extend beyond 10 TeV [24, 25]. Sources, such as Markarian 501, which emit photons above the TeV range are missed by experiments like CGRO.

The muons originating from such sources compete with a large background of down-going atmospheric cosmic ray muons. They can be identified if the collecting power and angular resolution of the detection system are good enough. The sources may also be highly variable, possibly producing a signal that stands out over a short period of time, only.

Since muons created in a photon shower originate from the decay of hadrons which are first photoproduced, the gamma-ray induced showers tend to be poor in muons. All secondary photons in a gamma-induced shower above the photoproduction threshold will contribute to the number of muons N_μ. The total number of muons in a shower is proportional to the photon energy E_γ. For muon energies recorded in CosmoLEP ($>$ 70 GeV) the number of muons e.g. in a 10 PeV photon shower with vertical incidence can be calculated [24] as:

$$\mathrm{N}_\mu(\mathrm{E}_\gamma, > \mathrm{E}_\mu) \;=\; \frac{2.14 \cdot 10^{-5}}{\mathrm{E}_\mu^2}\, \mathrm{E}_\gamma \qquad \text{with } \mathrm{E}_\gamma \text{ and } \mathrm{E}_\mu \text{ in TeV,}$$

to be about 40. The signature in CosmoLEP will be single-muon or multi-muon events. For the signal to stand out from a background uniformly distributed in space and time, a good angular resolution of the muon detection system is required. The tracking system of ALEPH (HCAL and TPC) and the extra muon chambers in the vicinity of ALEPH provide an excellent angular resolution of a few mrad. The pointing accuracy of the order of 10 mrad, for the muon momenta considered here, is dominated by multiple scattering in the overburden. For multi-muon events the positional accuracy gets much better. The effect of the Earth's magnetic field on the deflection of positive and negative muons is 10 mrad or less, depending on the energy.

For energies exceeding 100 PeV the transparency of the intergalactic medium improves (see Fig. 1.7) and one might see very energetic gamma-ray sources also out to larger distances. At these high energies the muon content of a photon shower is quite substantial, so that there is a possibility to also detect point sources with multi-muons. But even if no sources are found, the flux limits for active galactic nuclei (AGN), gamma ray bursters, supernova remnants and other potential sources are of fundamental interest. This is also true for limits on the flux of exotic particles from candidate sources. Air shower experiments, e.g. CASA-MIA [28], have not confirmed previously observed signals in the energy range above 10^{14} eV, and account for the fact that energetic gamma ray sources are usually variable and frequently sporadic. So there is much room for surprises.

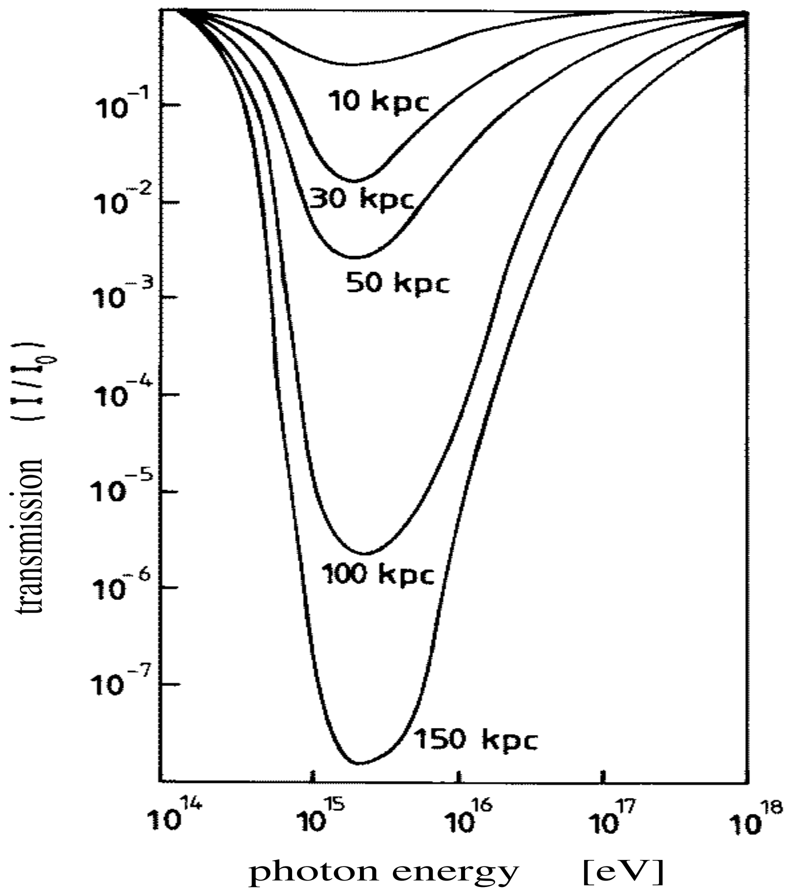

Figure 1.7. *Fractional absorption of high energy γ-rays by the 2.7 K blackbody radiation for different cosmic distances [26, 27].*

2 Analysis of Cosmic Ray data taken with the ALEPH detector

The present proposal was motivated in part by the intriguing high multiplicity cosmic ray muon events observed with the ALEPH detector [29]. The ALEPH Time-Projection Chamber (TPC) inside a solenoidal magnetic field of 1.5 Tesla provides a unique tool for study of the highest multiplicity muon bundles.

With the use of LEP experiments it is the first time that such a precise large area detector has been used for cosmic ray measurements. The analysis and results of the ALEPH data from the years 1997 and 1998 are briefly described in this section.

2.1 Data selection and reconstruction

The standard LEP triggers of ALEPH are sensitive to cosmic ray events, particularly multi-muon bundles, within a time window of a few microseconds around the beam-crossings. The events considered here were triggered by the energy deposition of cosmic ray muons in the electromagnetic calorimeter. They were selected from the LEP triggers by identifying events without a reconstructed vertex, with at least one well-defined track with momentum above 5 GeV/c and no track from the vertex region. This last vertex requirement was not applied to the high multiplicity muon events in order to avoid losing such events.

All muons were reconstructed and their common arrival time was determined either from the electromagnetic calorimeter or from tracks crossing the central membrane of the TPC. The flat time distribution of the events over a time interval of 2.5 μsec determined the duty cycle of 11% for cosmic ray data taking.

Some 370,000 events were selected in an effective data taking time of $1.06 \cdot 10^6$ sec. In most of these events the track information from the hadronic calorimeter and from the outside muon chambers were missing because their response time was much shorter than the sensitive time of the central TPC. A representative sub-sample of the data was scanned, as were all events with multiplicity greater than 6, in order to remove beam gas and muon interactions that can simulate high multiplicity events.

An example of one of the highest multiplicity events is displayed in Fig. 2.1 which presents views along and perpendicular to the LEP ring and along the shower direction. For this event the end-cap calorimeters and the forward muon chambers were in time and could be displayed. It becomes obvious that only a precise detector with a multiple hit capability like the TPC can resolve this enormous particle density.

The muons in these events are parallel and hence the shower direction was determined by averaging over all muon directions. The muon momentum is determined by the track fit. Due to the optimization of the ALEPH geometry for LEP events the best accuracy is obtained for tracks passing close to the vertex region. About 30% of all reconstructed tracks have a maximum detectable momentum above 1 TeV and were used for the muon momentum distributions.

2.2 The CORSIKA Monte-Carlo

In order to identify and study possible anomalies, the ALEPH data were compared with the expectations from cosmic ray air shower simulations. The current state of the art is represented by CORSIKA, a sophisticated simulation program developed in recent years by the KASCADE group in Karlsruhe [30]. It describes the interactions of the primary particles at the top of the atmosphere and follows the electromagnetic and hadronic cascades through the atmosphere down to the observation level.

The results presented here are based on using the QGSJET model. Other models are also available. It must be emphasized that all models require extrapolations to high energies and in the forward direction involving some degree of theoretical prejudice. Similar expectations will yield similar results, but may still leave room for surprises when compared to the real world.

Only the hadronic component with the hadrons decaying into muons was followed since contributions from the electromagnetic component are negligible. A momentum cut of 70 GeV/$\cos(\theta)$, where θ is the zenith angle of the muon, was applied to account for the energy loss in the overburden of ALEPH. To obtain good statistics over the entire relevant energy range ($10^{12} - 10^{18}$ eV) the interactions were generated in primary energy bins and weighted according to the cosmic ray spectrum (Fig. 1.2). The shower axes were scattered over an area of 200 x 200 m^2 centered around the ALEPH detector and the muons hitting the sensitive area of the TPC (16 m^2 , almost independent of the zenith angle) were registered. Monte-Carlo data sets comparable in size to the actual data set were generated for both primary protons and primary Fe nuclei.

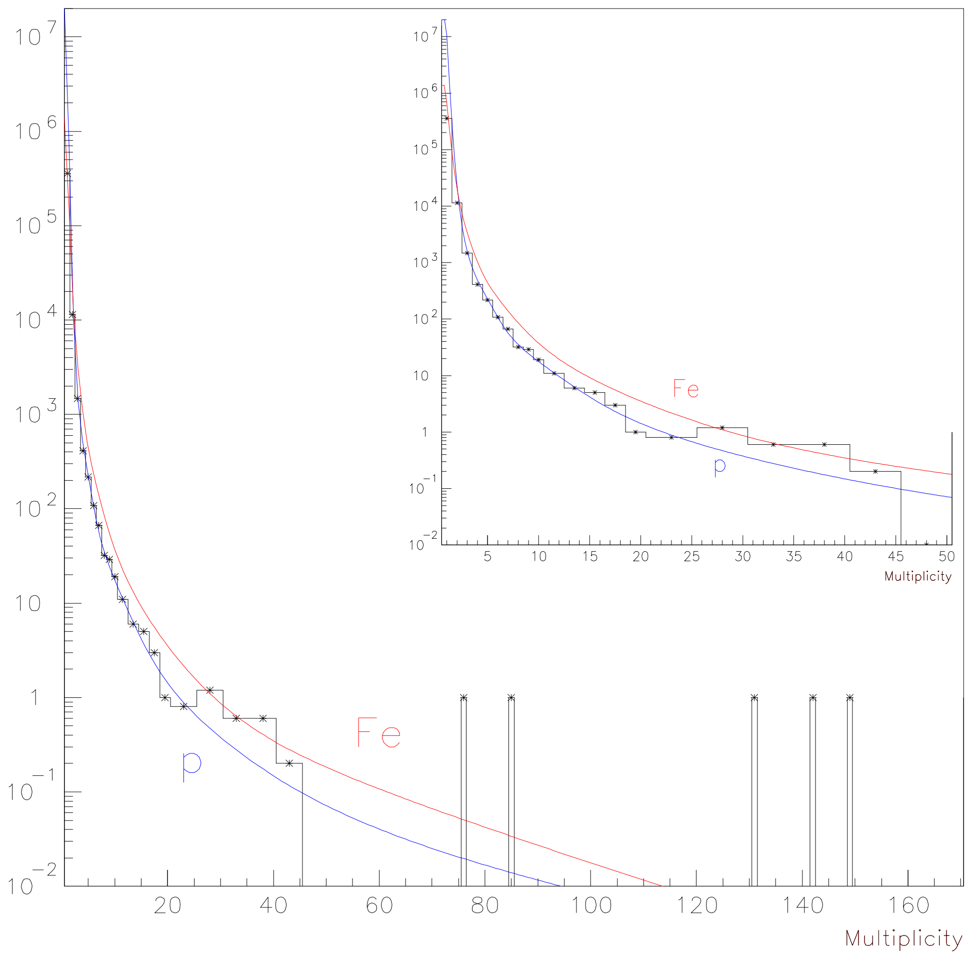

Figure 2.2. *Multiplicity distribution of muons in the TPC compared to CORSIKA simulations for p and Fe as primary particle. The highest multiplicity event has twice the particle density (see Tab. 2.1 and Fig 2.4).*

event	muon density (m^{-2})	zenith angle (^{o})	primary energy (eV)
97-a	4.75	40.8	$3 \cdot 10^{16}$
97-b	5.3	37.7	$3 \cdot 10^{16}$
97-c	8.9	40	$6 \cdot 10^{16}$
98-a	8.2	48.6	$7 \cdot 10^{16}$
98-b	18.6	27	10^{17}

Table 2.1. *Characteristics of the highest multiplicity events. The primary energy was estimated by assuming the shower center to be close to the TPC and taking into account the zenith angle.*

2.3 Results

After a check of the consistency of the two data sets, the '97 and '98 data were combined and compared with the CORSIKA simulation. Fig. 2.2 shows the measured distribution of the muon multiplicity in the TPC and the CORSIKA simulation for proton and iron as primary particles, absolutely normalized with the effective running time for energies above $3 \cdot 10^{14}$ eV. Iron induced showers are more effective in producing muons since they interact higher in the atmosphere and also lead to larger pion multiplicities.

The single muon rate of the simulation agrees with the scintillation counter measurement by CosmoALEPH which has obtained a muon flux in the cavern of 0.4 m^{-2} sr^{-1} sec^{-1} for almost vertical incident angles. The efficiency of the LEP triggers is low for single muons but approaches 100% for around three muons. Up to a multiplicity of 20 the proton curve describes the measurement well over several orders of magnitude, indicating that the primary spectrum is dominated by light elements at the corresponding energies. Above a multiplicity of 20 there is evidence for a transition to the Fe curve. However, the five highest multiplicity events are above the expectation from the simulation. This is better demonstrated with the integral distribution in Fig. 2.3, which is plotted in double logarithmic scale for zenith shower angles below and above 30^o.

It is worth noting that four of the five highest multiplicity events have zenith angles beyond 30^o. Tab 2.1 summarizes the characteristics of these events. An estimate of the primary energy, under the assumption that the shower center is close to the TPC, is also given. If the shower core were further away, the energies would be even larger; the energy estimate was done for proton induced showers and would be 40% lower for iron. While the simulation agrees with the data over a wide multiplicity range, it fails to describe the highest multiplicities for primary particle directions above 30^o, even under the assumption of a pure iron composition.

The highest multiplicity event contains about 150 muons in only one half of the TPC since the other half could not been read-out due to data overflow. This event with the outstanding muon density of some 20/m^2 is displayed in Fig. 2.4.

The muon density grows almost linearly with the primary energy and hence multiplicity bins are equivalent to energy bins. The contribution of different energy intervals of the primary spectrum to the muon multiplicity in the TPC is shown in Fig. 2.5 for proton induced showers. Multiplicities above 5 and 20 are testing the energy spectrum around 10^{15} eV and 10^{16} eV respectively, thus covering the interesting region around and above the knee. Measurements of the particle composition as well as theoretical prejudices about the acceleration mechanism of cosmic rays suggest an increase of the heavy component above 10^{16} eV, not in contradiction with our multiplicity spectrum.

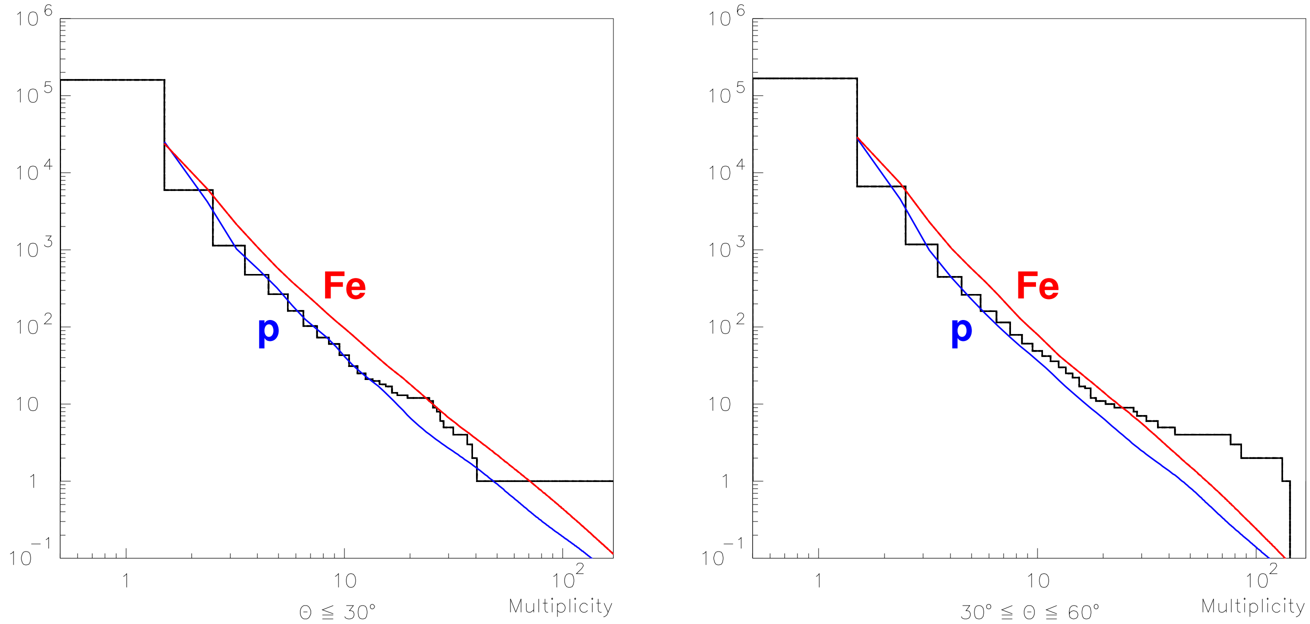

Figure 2.3. *Integral multiplicity distributions of muons in the TPC for two different zenith angle intervals ($\theta < 30^o$ and $30^o < \theta < 60^o$) compared to CORSIKA simulations for p and Fe. Power law fits of the M.C. curves yield an exponent of about -1.8.*

Powerlaw fits to the integral multiplicity distribution in Fig. 2.3 yield an exponent of -1.8 which is close to the one in the primary energy spectrum confirming that multiplicity and primary energy are correlated.

The primary particle direction is determined by an average over all muon directions, which are parallel to within a few degrees within a single event. The zenith angle (θ) distribution, follows a power law in the variable $\cos^n(\theta)$, where the exponent n is close to 2 for single muons. For multi-muons this exponent is n=3.2 as can be deduced from Fig. 2.6 where the measured $\cos^n(\theta)$ distribution is compared to the simulation.

In order to search for point-like sources in the universe, the muon bundle directions are transformed into galactic coordinates. The events with multiplicity $N \geq 3$ and the high multiplicity ones ($N \geq 20$) are plotted in Fig. 2.7. The events are not clustering nor do they point to known photon sources in our galaxy or nearby galaxies (<100 Mpc). Some of the known galactic and extragalactic sources are marked with letters.

With the use of the LEP detectors, it is possible for the first time to measure the momenta in cosmic ray multi-muon events over a sizeable detector area. The ALEPH detector is optimized for tracks coming from the vertex and hence only muons passing close to the vertex region are well measured. We applied a momentum accuracy cut of $\Delta p/p^2 < 10^{-3}$ which is fulfilled by 35% of the tracks. Scaled with the above efficiency factor, the momentum distribution up to 1 TeV is given in Fig. 2.8 for different bins in multiplicity.

The momentum distribution is flatter for multi-muons than for single muons. This is well described by the simulation which is absolutely normalized. The higher momenta of multi-muons can be qualitatively understood since these muons are closer to the shower core. They also arise from larger primary energies and originate from earlier stage of the shower development. Momentum correlations will be studied event-by-event in order to better locate the shower core.

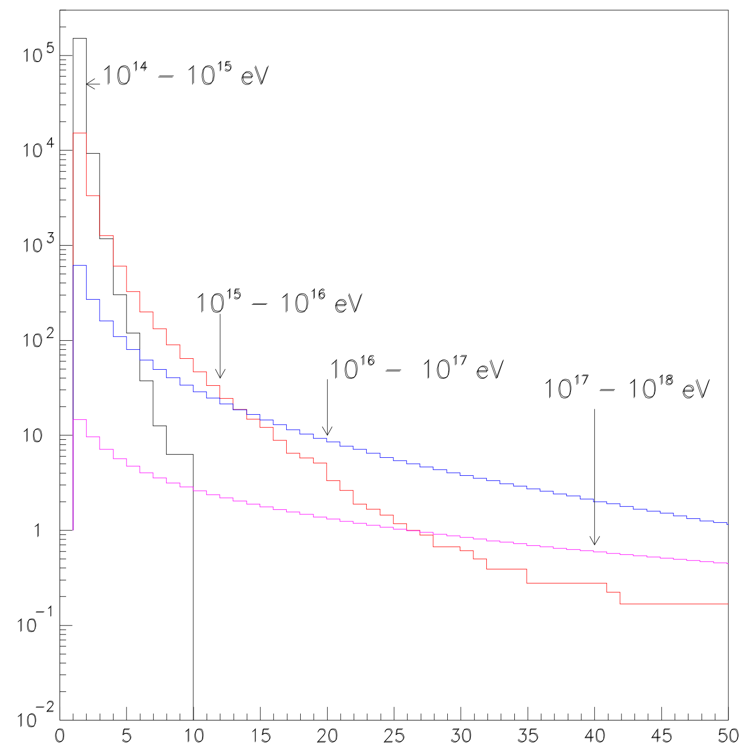

Figure 2.5. *Contribution of the different energy intervals of the primary spectrum to the muon multiplicity.*

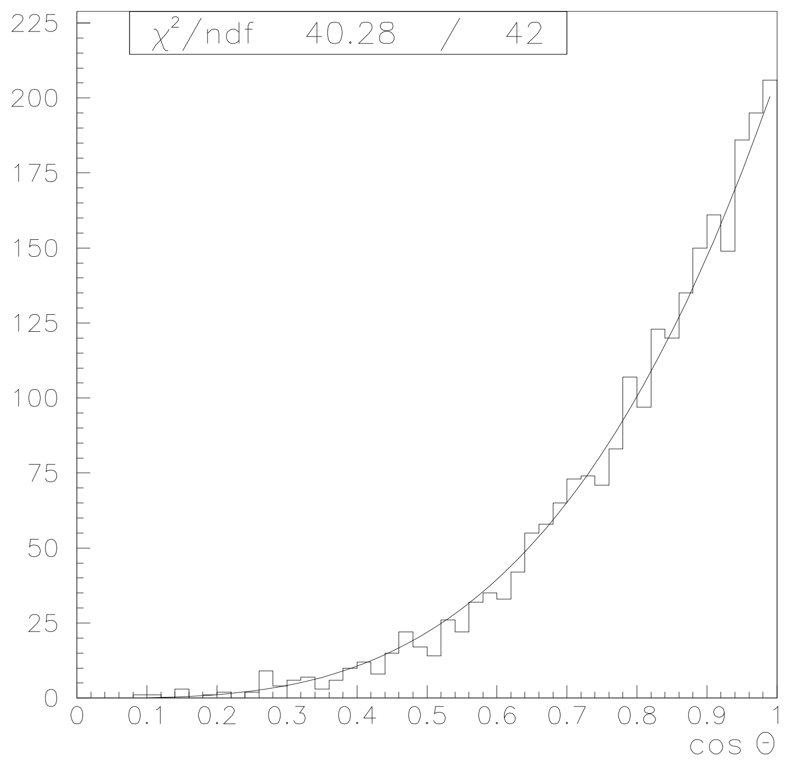

Figure 2.6. *The zenith angle distribution of multi-muon bundles with more than two muons, compared to the simulation, which can be fitted by a powerlaw in* $\cos^n(\theta)$ *with an exponent* n*=3.2*

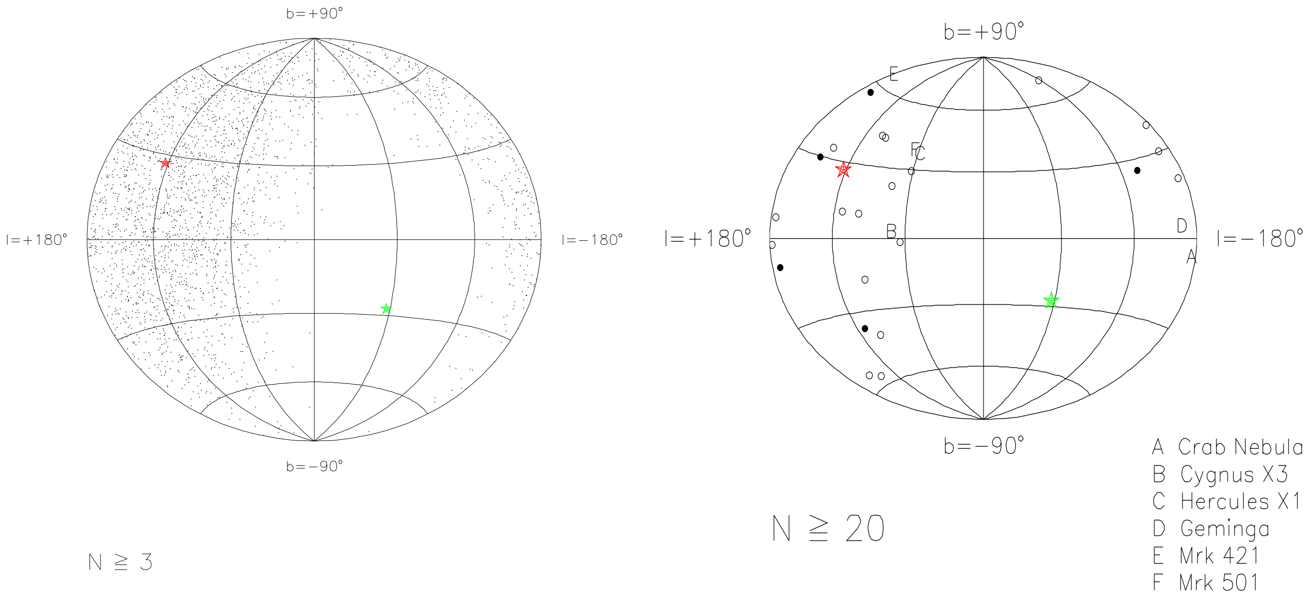

Figure 2.7. *Apparent origins of the events on the sky in galactic coordinates for multiplicities* $\geq$ *3 and* $\geq$ *20. In the second picture the five highest events are shown as filled circles. The asterisks indicate the positions of the Celestial North and South pole, some important known gamma ray sources visible from our detector's position are given as letters (A-D: galactic,E-F: extragalactic).*

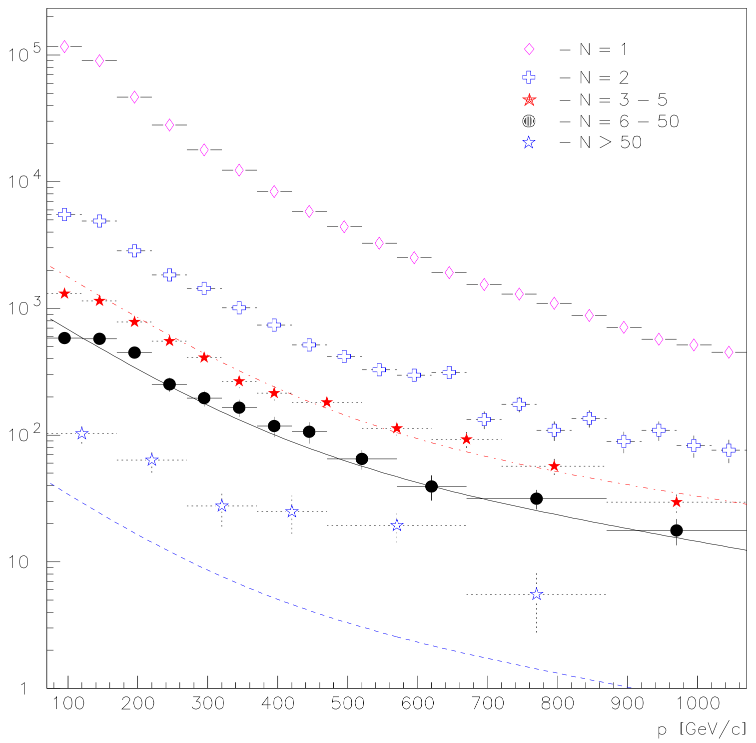

Figure 2.8. *Momentum distributions of muons in the ALEPH TPC for several multiplicity bins. The energy loss in the overburden has been compensated for by adding 70 GeV/*$\cos(\theta)$ *to the measured momenta. The lines for the multiplicity bins* $n \geq 3$ *represent the simulation for proton primaries, absolutely normalized*

3 The proposed muon array

3.1 The principal measurements

The principal thrust of the CosmoLEP proposal is to extend the ALEPH detector with additional muon chambers in order to increase the statistics and to study the radial structure of muon bundles over a larger area. This is particularly critical in order to further study the intriguing high multiplicity events observed with the ALEPH detector. The specific proposal, a 200 m^2 muon chambers array close to the ALEPH detector, is sketched in Fig. 3.1.

There are at least two reasons for proposing such an array. First, because the new muon array has an effective area one order of magnitude greater than the ALEPH detector, and, because it has a duty cycle of 100%, the statistics of the high multiplicity events can be improved by a factor of 100 within one year of data taking. If the five highest-multiplicity events observed by the ALEPH detector are not statistical fluctuations, we will have a data sample of a few hundred of such high multiplicity events which will permit a detailed study of their character.

Second, the study of the radial distribution of the muons in these events using the proposed array together with the ALEPH detector should permit discrimination between various models, such as new forward production phenomena or very high energy primaries ($\sim 10^{16-17}$ eV), which may account for the anomalous high-multiplicity events. This sensitivity is illustrated in part by Fig. 3.2, where the muon density for proton induced showers, as predicted by the CORSIKA Monte-Carlo simulation, is plotted for various energies as a function of the radial distance to the shower center; the lines are 3-parameter fits which describe the density dependence from radius, energy and incident angle. The muon density is falling rapidly with distance, dropping by an order of magnitude over the 20 m distance between the ALEPH detector and the muon array. In order to probe the nature of the highest multiplicity events, it is therefore essential to study the structure of these events and to determine the core position of the muon shower and the primary particle energy.

3.2 The muon array in the ALEPH experimental cavern

The proposed array, consisting of eight modules of approximately 200 m^2 is illustrated in Fig. 3.1 (more precisely, the array has an active area of 160 m^2, spread over 250 m^2). Note that we have put the muon array as close as possible to the ALEPH detector. This is mandatory for the study of the structure of the high multiplicity events triggered by the ALEPH detector.

Each of the modules consists of two (or perhaps three) large area drift tube chambers mounted on top of each other, together with a trigger counter hodoscope. This is illustrated in Fig. 3.3.

The muon chambers were originally used in the UA1 experiment [31], and have been used more recently in NOMAD. These chambers are composed of individual extruded aluminium tubes which are glued together to form a rigid and self-supporting chamber body of four layers. A track is then measured in two orthogonal projections with 4 (or perhaps 6) planes per projection. Two adjacent planes of staggered tubes help to solve the left-right ambiguity inherent to drift chambers and to overcome the inefficiency due to the gap between the tubes. The chambers are placed with a precision of better than 1 mm with respect to each other via distance pieces linked to the four precise fiducial plates glued on the chambers.

The chambers are presently being tested in the BEBC hall with a non-flammable gas mixture of Ar (90%) and CO^2 (10%). Initial results indicate a spatial resolution of better than 1 mm and an efficiency of more than 90% over the entire drift tube. The drift times are digitized with a precision of 1 nsec by TDC's previously used by NOMAD.

The TDC's are capable of resolving up to 16 hits per wire, which in principle will allow the

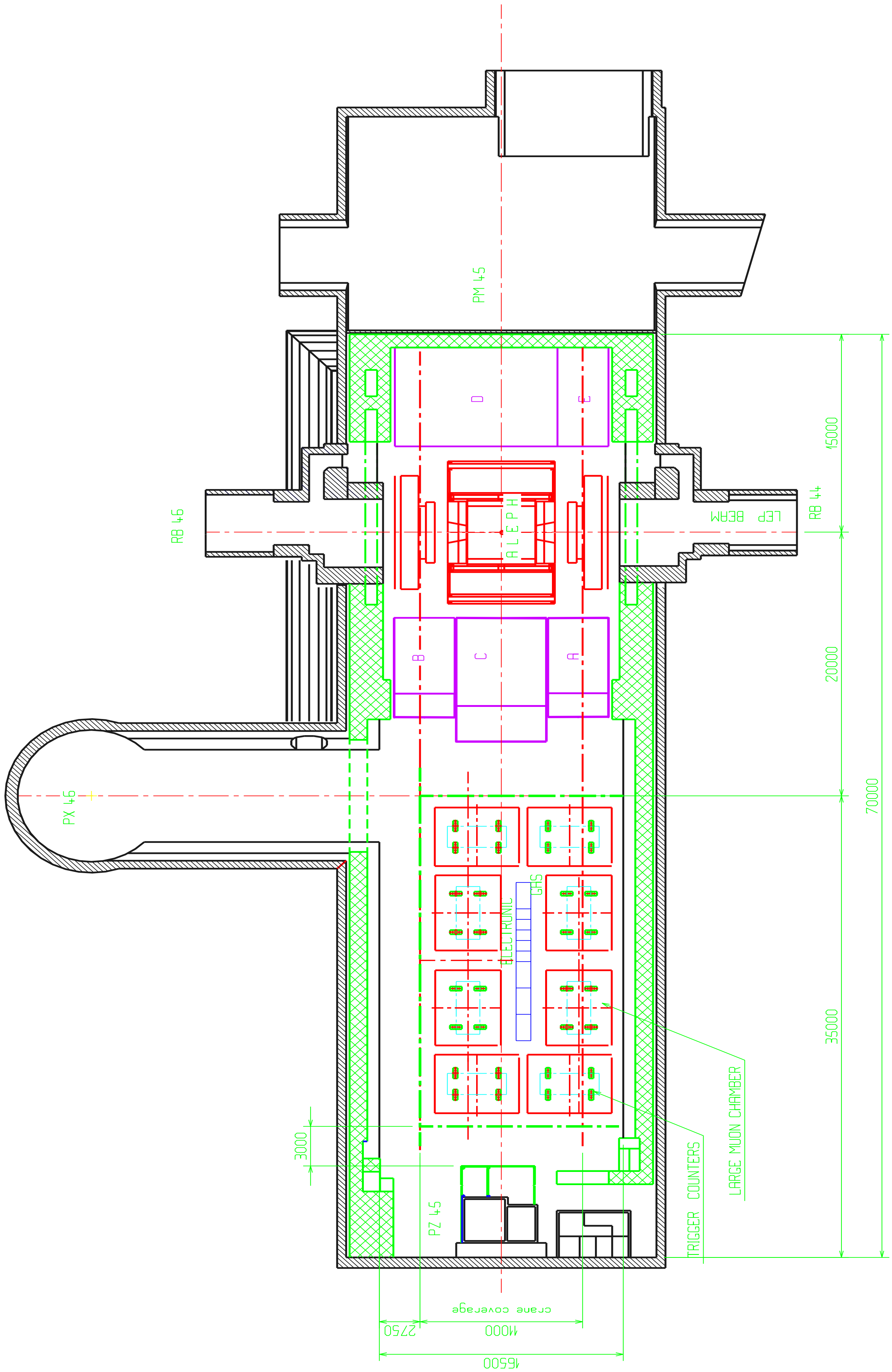

Figure 3.1. *Proposed muon chambers array in the ALEPH underground cavern*

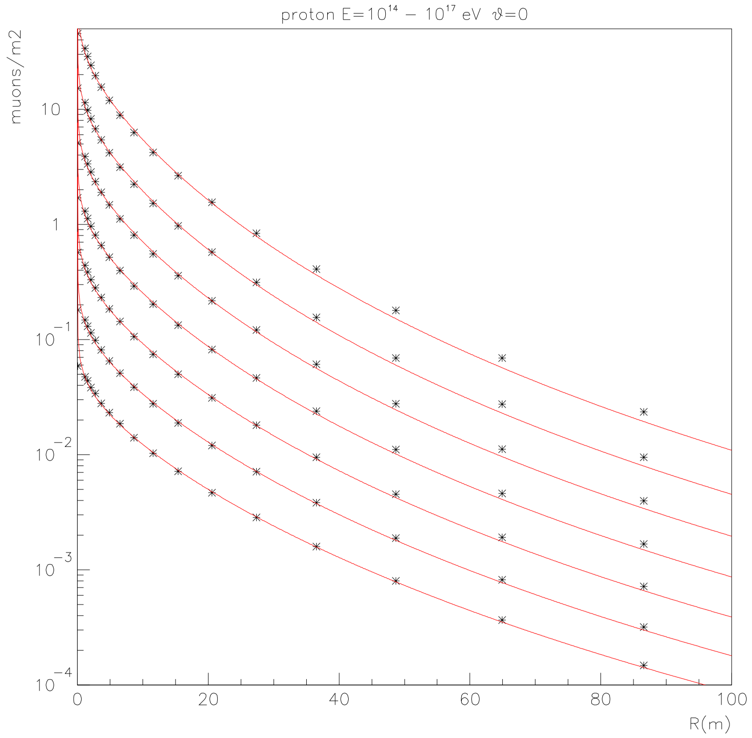

Figure 3.2. *CORSIKA Monte-Carlo simulations of the muon density for proton induced showers of various energies as a function of the radial distance from the shower center (the energies are: 10*^{14},$3 \cdot 10^{14}$,*10*^{15}*.....10*^{17} *eV).*

resolution of individual muons up to densities of a few hundred per chamber. We are presently working on the problem of pattern recognition in large multiplicity events, taking advantage of the fact that the tracks are parallel to within a few mrad. The outcome of this study will determine whether two or three chambers will be mounted on top of each other in each module. It will also determine the maximum muon density that can be realistically reconstructed.

3.3 Muon Array Trigger

Each module has a single layer of trigger counters covering some 20% of the module surface. These counters were used in NOMAD and have been loaned to CosmoLEP by the Padua group. The sizes of the individual counters vary but they are typically 2 m long and 20 cm wide. Photomultipliers are mounted on both ends of each counter. The signals from the photomultipliers are put into coincidence using mean-timers, yielding a precise timing.

The trigger should select primary interactions with an energy above 10^{15} eV and with the shower core preferably close to or inside to the chamber array. Such high multiplicity events are triggered on by requiring an n-fold coincidence among the total of 60 counters. Varying the value of n corresponds to varying the minimal muon density which will be triggered on.

The CORSIKA Monte-Carlo simulation has been used to study the performance of these triggers. Events were selected where the shower core falls within an area of 24 x 14 m^2 centered on the chamber array and hence the core position and energy can be determined. Fig. 3.4 shows the effect of the n-fold counter coincidence on the primary cosmic spectrum.

With larger values of n the effective energy threshold on the spectrum is increasing. Muon showers at larger distances and with higher energies also contribute to the trigger, as can be

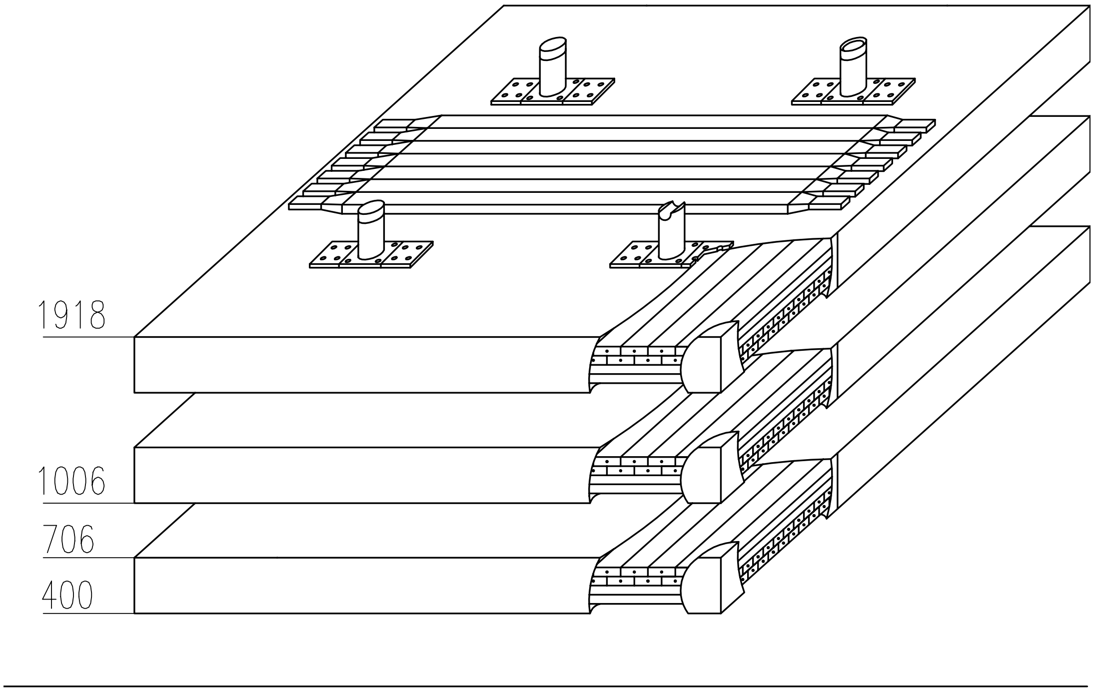

Figure 3.3. *Sketch of a muon chamber module, consisting of three precisely mounted chambers on top of each other and a trigger counter hodoscope. The numbers on the left side refer to the height in mm.*

concluded from the spectrum for the case where the shower core is within an area of 100 x 100 m^2. The trigger condition $n \geq 4$ seems reasonable since it suppresses low energy showers with a low muon density, but is is fully efficient for showers within the chamber array and with energies around the cosmic ray knee. The highest energy showers above 10^{16} eV can extend over the larger area still fulfilling the $n \geq 4$ trigger condition. To further illustrate the trigger acceptance Fig. 3.5 displays the shower core positions for two energies and the 4-fold trigger coincidence.

It is of utmost importance that the high multiplicity events recorded during normal LEP data taking in the ALEPH detector also trigger the CosmoLEP muon array. Every ALEPH-LEP trigger has also to trigger the CosmoLEP muon array. While the timing of these events is unknown to better than a few microseconds, the drift time digitizers have a sufficiently wide window (64 μsec) that the muons will still be recorded. Furthermore, we would benefit from specially scheduled cosmic ray runs of the ALEPH detector where the duty cycle for cosmic data is 100% and where, in addition, the ALEPH detector can be triggered by the new array.

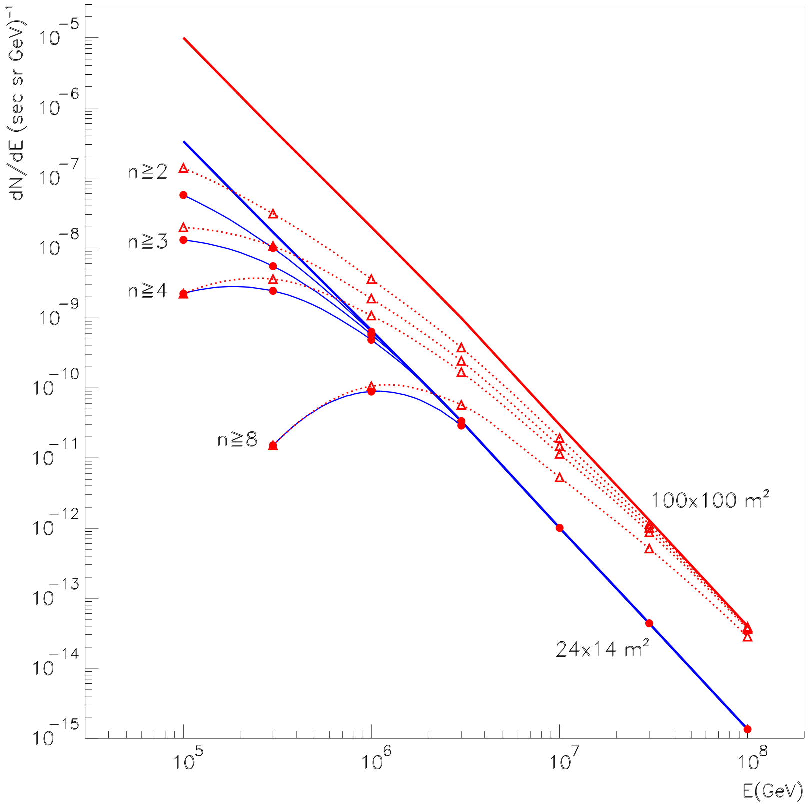

Figure 3.4. *The primary cosmic ray energy spectrum for two arrays and the effect of a n-fold coincidence (as described in the text) on it.*

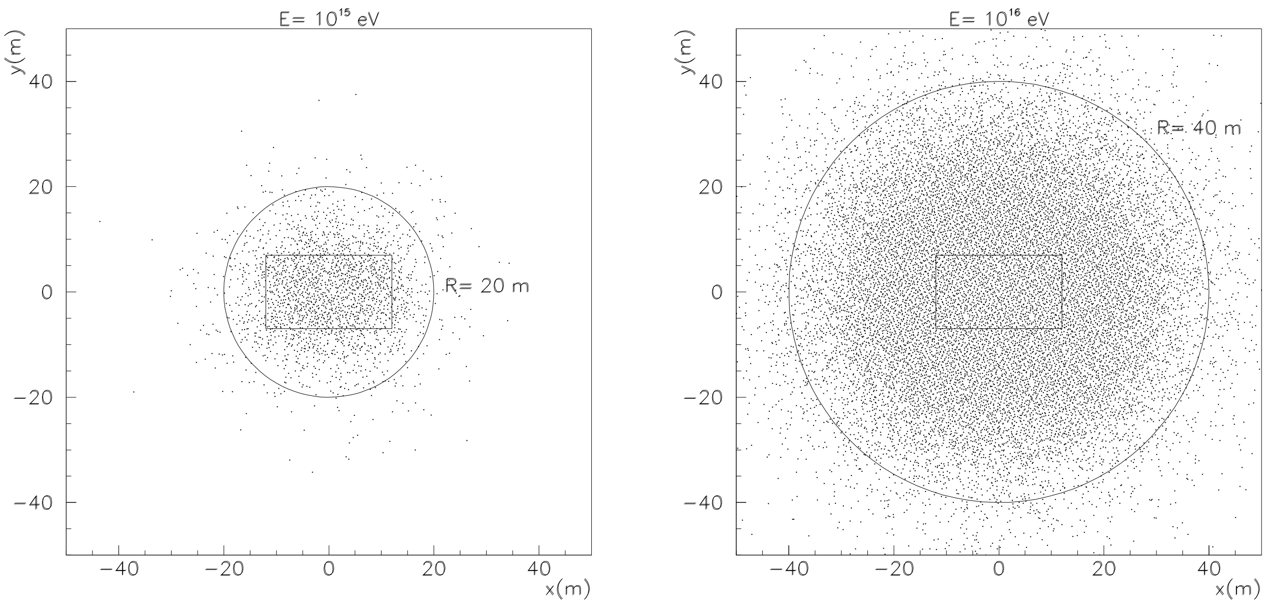

Figure 3.5. *Shower core positions for two energies and the 4-fold trigger coincidence.*

4 Performance Simulations

The proposed chamber array, operating in conjunction with the ALEPH detector, will study the structure of muon bundles in order to determine the core position and the primary energy of the shower, and to distinguish, at least on a statistical basis, between proton and iron induced showers. The CORSIKA air shower Monte Carlo was used to study the performance of the proposed set-up.

Already with the limited statistics of the data from ALEPH, we observed a transition in the multiplicity distribution from proton to iron induced showers at large multiplicity (see Fig. 2.2). The equivalent distribution for the new array with 8 modules is given in Fig. 4.1 for the four-fold coincidence trigger described in section 3.3. The ten times larger detection area shifts the average multiplicity to larger values and furthermore low multiplicities are suppressed by the trigger condition, which becomes fully efficient only at primary energies above 10^{15} eV. (see Fig. 3.4). With an assumed measurement time of $2 \cdot 10^7$ seconds, the new data set will be 100 times larger and hence will permit a detailed study of the transition from proton to iron. The contributions of different energy intervals to the multiplicity distribution can be deduced from Fig. 4.2. Each energy bin contributes to a certain multiplicity range. The experiment is sensitive to energies between 10^{15} and 10^{17} eV. However, few events with energy above 10^{17} eV will be collected. Fig. 4.3 shows the multiplicity distribution for individual modules, which have a detection area similar to the ALEPH TPC. In the case of the highest multiplicities, it will be a challenge to reconstruct (rather than just estimate) the actual multiplicities, even if the muon direction is known.

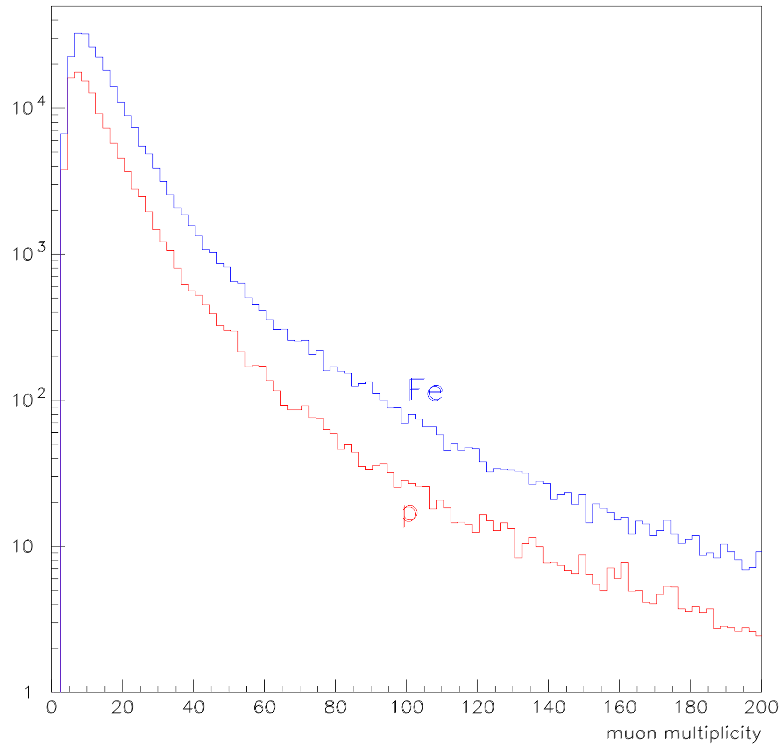

Figure 4.1. *The distribution of the multiplicity in the new array with 8 modules for the four-fold coincidence trigger described in section 3.3*

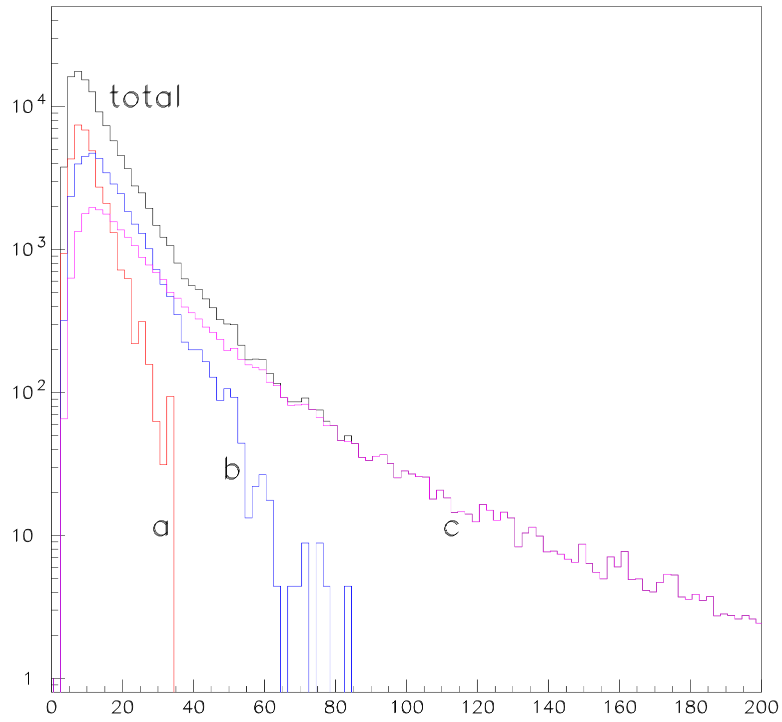

Figure 4.2. *Contributions of different energy intervals to the multiplicity distribution. (a) 3·*$10^{14} < E < 10^{15}$ *eV; b) 10*$^{15} < E < 3 \cdot 10^{15}$ *eV; c) 3·*$10^{15} < E < 10^{17}$ *eV.)*

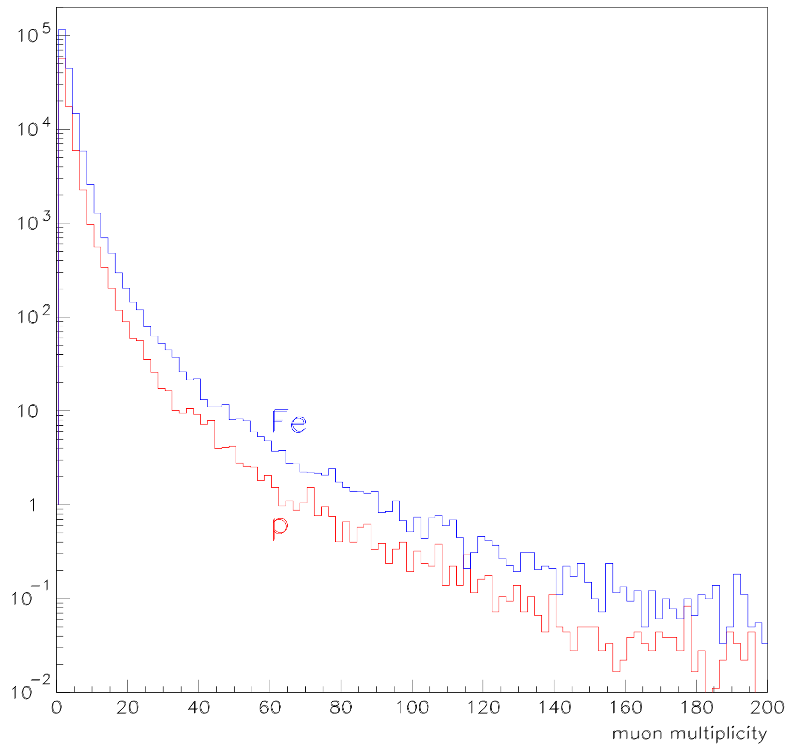

Figure 4.3. *The multiplicity distribution for individual modules, which have a detection area similar to the ALEPH TPC, for the four-fold coincidence trigger.*

The size of the new array will permit the reconstruction of the shower core and the determination of the primary energy provided the shower core falls within or close to the array. As an example, the multiplicity distributions in bins of 1 m in the two projections of the chambers are shown in Fig 4.4 for two core positions inside the array. The distributions are clearly distinguishable and will allow a determination of the location of the shower core. For core positions outside the array, the muon distributions become flatter and the energies needed to produce a given multiplicity in the array become larger, making the reconstruction more uncertain, but not impossible.

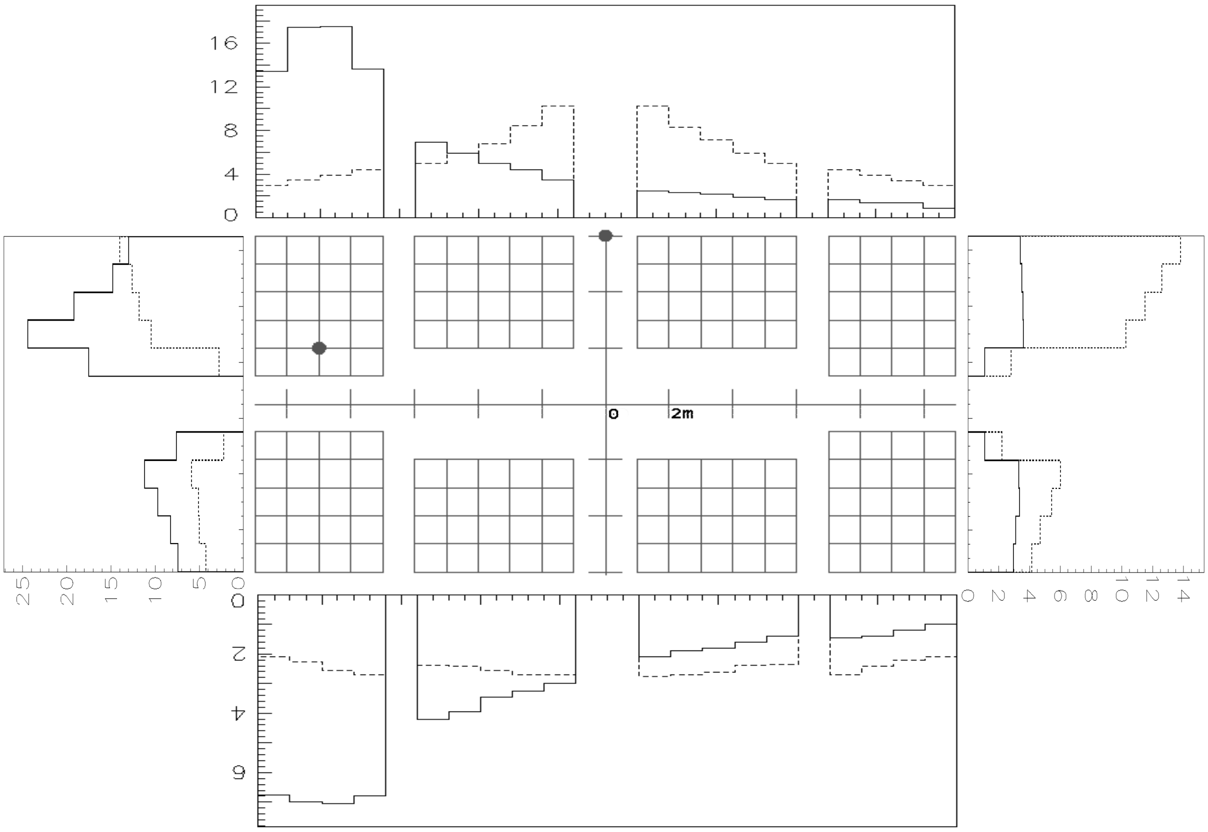

Figure 4.4. *Simulated muon distributions in the left, right, upper and lower half of the proposed array for two different showers (p, 10^{16} eV). The dots indicate the core positions.*

For a given energy, the multiplicity per chamber and the density distributions are calculated for a grid of core positions. These averaged distributions are then compared to the measured distribution on an event-by-event basis to obtain the core position, which is the grid position with the smallest χ^2. The difference between the real and the estimated position is plotted in Fig. 4.5 for vertical proton induced showers at two energies. Similar results were obtained for iron. The distributions have a Gaussian shape with some tails. The average precision amounts to about 1.5 m, which can probably be improved by applying a finer grid structure. Moreover, the higher is the energy, the better the shower core can be determined, as a consequence of the increasing muon density. The precision is decreasing for cores outside the array except if they are situated between the array and the ALEPH detector. In this case the multiplicity in the ALEPH TPC will improve the situation considerably. Furthermore, scintillation counters, such as those from HEGRA, which could be placed around ALEPH and the array in a later stage, would give additional information about the core position and would help the reconstruction.

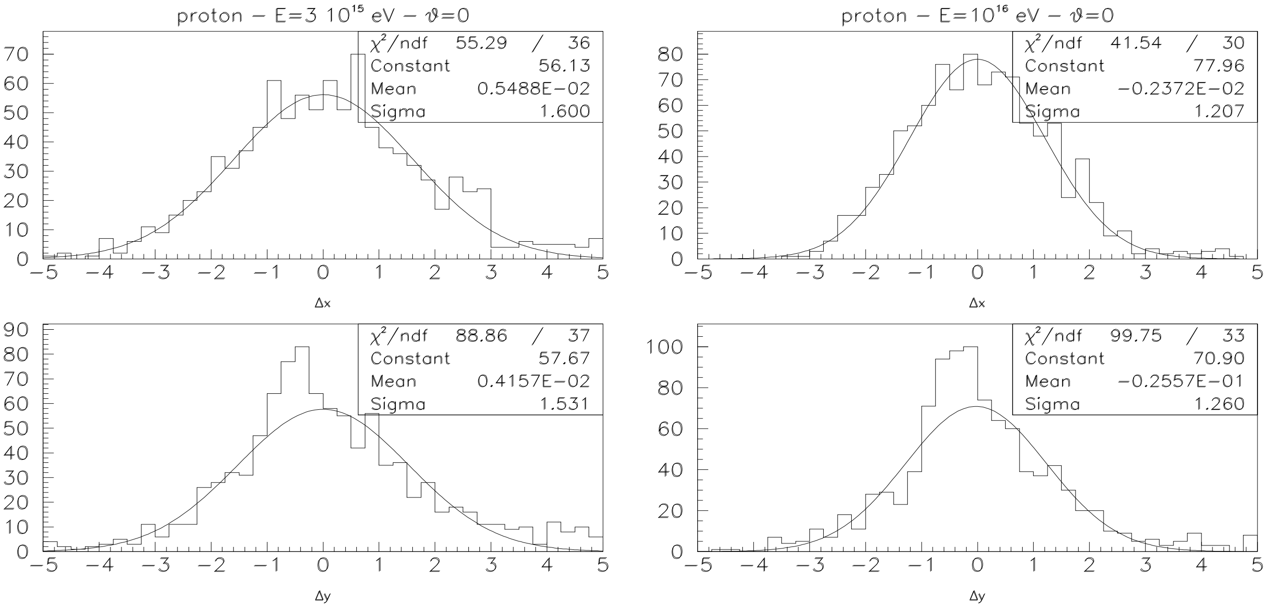

Figure 4.5. *The difference between the real and the estimated positions of shower cores for vertical proton incidence at two energies.*

The total number of muons in the array is almost independent of the core position for distances below 10 m from the array center but it decreases significantly at larger distances. This is shown in Fig. 4.6 for proton and iron induced showers. The indicated fluctuations of individual measurements demonstrate that the primary energy can be estimated to within 40% from the total number of muons alone. An uncertainty of about 30% has to be added to account for the difference in the energy calibration for proton and iron induced showers, if they cannot be identified. It has, however, to be stressed that the energy calibration and the shower profile depend strongly on our knowledge about the interactions in the upper part of the atmosphere.

Once the shower core is determined, the radial muon density distribution can be used to determine the primary particle energy and the particle type. The central density is proportional to the energy, and it depends only slightly on the primary particle (Fig. 1.5). However, the fact that the radial distribution is considerably flatter for iron induced muon bundles is the key to discriminating between proton and Fe induced showers. As an examples, the individual muon distributions in the chambers of the array and not only the total multiplicity, are different for proton and iron showers and hence it will help to discriminate between them. The lowest χ^2 for the grid position closest to the shower core will therefore depend on the primary particle type. Applying cuts on this value, which reduce the statistics to about 35%, we were able to identify correctly 78% of the particles.

Correlations between the multiplicities in ALEPH and the muon array are important for the identification of the primary particle. For the case in which the ALEPH detector is triggered by a muon bundle, the proposed array is ideally located at distances from 20 to 40 m. The shower curves differ by more than a factor 2 for proton and iron at these distances (see Fig. 1.5). As a consequence of the steeply falling energy spectrum, the shower core is often close to ALEPH for large multiplicities. Furthermore, the particle momenta yield additional information about the distance to the center. As demonstrated with the simulation in Fig. 4.7, muons in the center have,

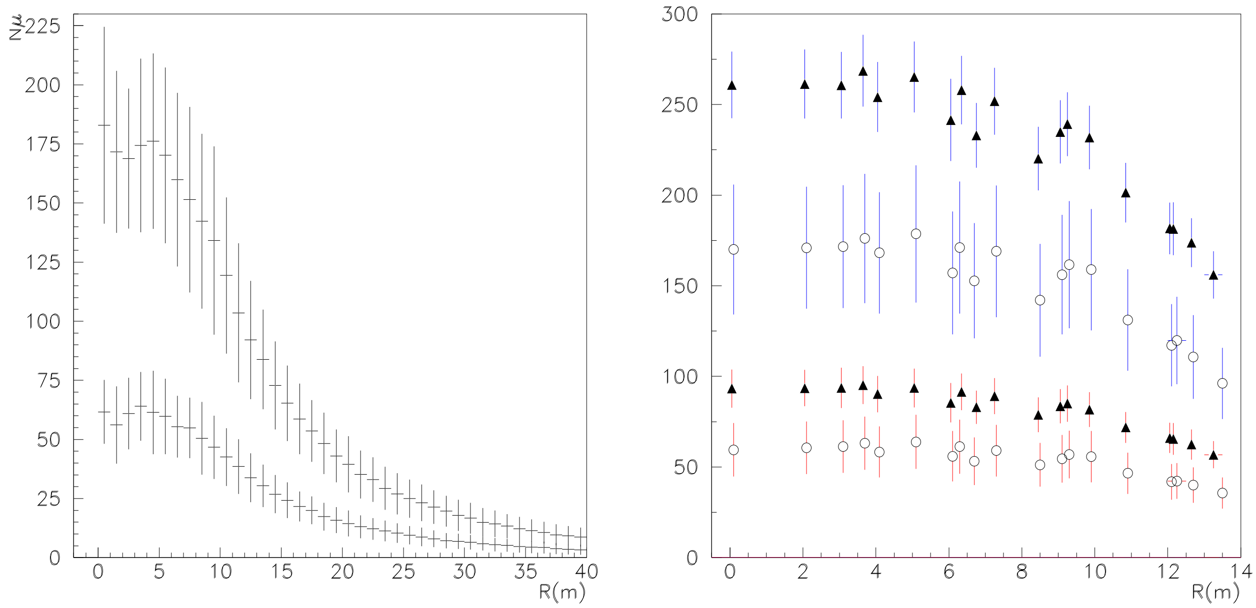

Figure 4.6. *Total multiplicity in the array as a function of the core distance to the array center for protons (left) and protons (open circles) compared to iron (triangles) inside the array (right). (Primary energies: E= 3* $\cdot 10^{15}$ *and* 10^{16} *eV).*

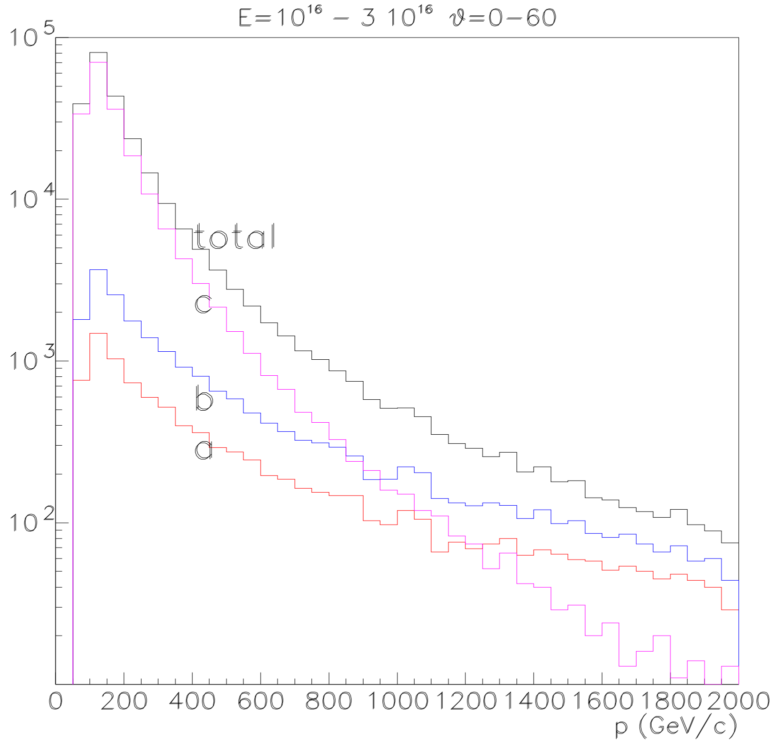

Figure 4.7. *Momentum spectrum of muons for different core distances (Monte-Carlo); a) R<* $3m$ *; b) R<* $5m$ *; c) R>10 m*

on average, higher momenta than those outside the core. This is confirmed by the momentum measurements with the ALEPH detector which shows a flattening of the spectrum for high multiplicity events (Fig. 2.8). Thus the measured radial distribution for these events will allow some conclusions about the primary particle.

Much work still has to be done to characterize the structure of the multi-muon bundles, to compare with the different interaction models, to search for deviations and to then extract the relevant parameters such as the primary energy and the particle composition. The considerations mentioned above only illustrate the possibilities of the new detectors proposed by CosmoLEP.

5 Time coincidences over large distances

As a consequence of the momentum cut-off of 70 GeV at the ALEPH detection depth, the muon density of "standard" extensive air showers decreases rapidly with the distance from the shower axis. Most of the muons are confined to less than a few hundred meters in radius, as illustrated in Fig. 5.1, where the radial muon distribution is shown for distances up to 1 km. Events spreading over much larger distances would therefore be unexpected and indicative of extra-atmospheric radiation, created, for example, in cosmic beam dumps [32], in interactions of highest-energy cosmic nuclei with interstellar matter or from energetic cosmic dust grains which have partially disintegrated at a large distance from earth. First indications of time correlations in cosmic rays over distances as large as a few hundred km have been reported by a Japanese [33] and a Swiss group [34]. The original idea of CosmoLEP [2] was to search for such events using the four LEP detectors. This would imply that each LEP experiment must have a 100% duty cycle for cosmic ray triggers independent of the LEP beam crossing. The synchronization would then be achieved off-line by time stamps from the Global Positioning System (GPS) which are recorded together with each cosmic ray event.

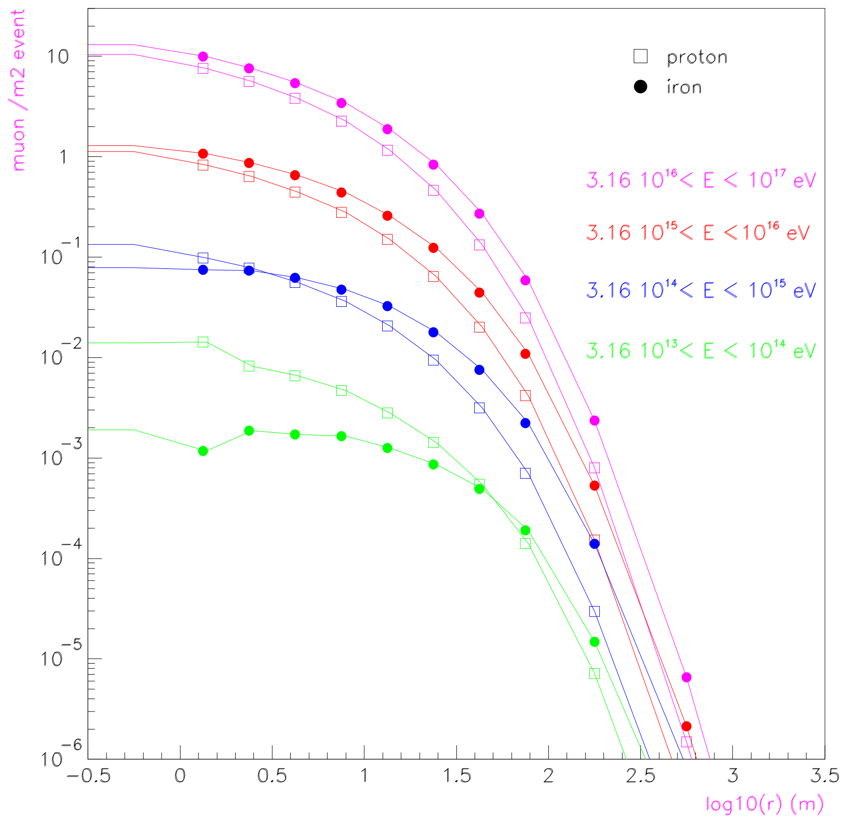

Figure 5.1. *Radial muon distribution for proton and iron induced showers for different energy ranges.*

5.1 CosmoALEPH, a pilot experiment for CosmoLEP

At the time, in 1993, when the search for large distance coincidences using the LEP detectors was first suggested, only ALEPH was able to provide an independent cosmic ray trigger with

100% duty cycle. Hence some ALEPH members started a pilot experiment (CosmoALEPH) [2] as a feasibility study agreed upon by the LEPC and the Research Board [35]. The experimental set-up of CosmoALEPH covers the barrel hadron calorimeter of the ALEPH detector and five scintillator stations in the neighbourhood of ALEPH. The schematic lay-out is shown in Fig. 5.2. The whole array spans distances between 18 and 1150 m.

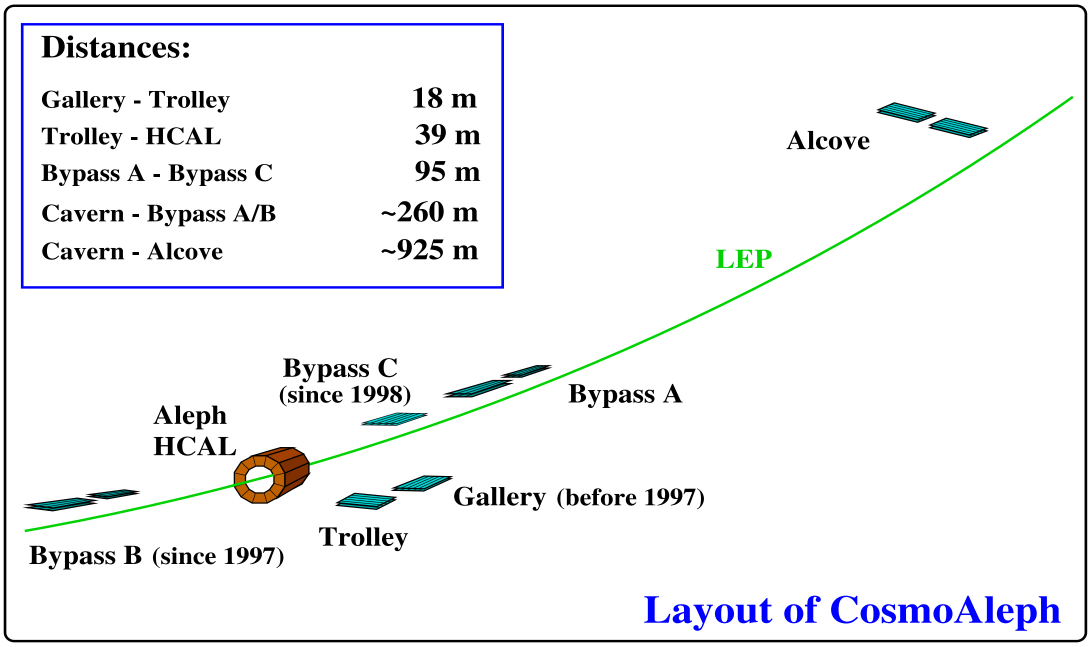

Figure 5.2. *Layout of the CosmoALEPH experiment*

All detectors have a stand-alone data acquisition system. Each scintillator station consists of several stacks of two scintillators which are read out by photomultipliers at both ends. A station is read out when at least one stack has a coincidence between its 4 photomultipliers. The HCAL trigger requires a penetrating track through the barrel. Since 1998 the GPS time is also read out. Data were taken during various periods since November 1995 with an integrated opentime of 100 and 173 days for different station pairings. Double-coincidence rates were measured between stations as far apart as 526 m. Triple coincidences were also observed. One remarkable event fired three stations extending over 1150 m . Preliminary results have been reported at several cosmic ray conferences [36]. The normalised double-coincidence rates as a function of distance between station pairs are shown in Fig. 5.3. They are compared with simulations from a fast Monte Carlo, called SAM (Simulation of Atmospheric Muons [37]) which uses the radial muon distribution from CORSIKA for proton and iron primaries. Coincidences are confined to distances of less than 500 m, and can probably be understood as coincidences between muons originating in the same atmospheric shower. The simulation was done for proton and iron as primary particles and for an energy independent mixture of the two. The substantial difference in the coincidence rates between proton and iron induced showers gives hope that a precise measurement will distinguish between these two components.

5.2 CosmoLEP proposal for large distance coincidences

Since the early proposal of CosmoALEPH as a pilot experiment for CosmoLEP the situation for coincidence measurements in the LEP tunnel has considerably improved. Besides ALEPH,

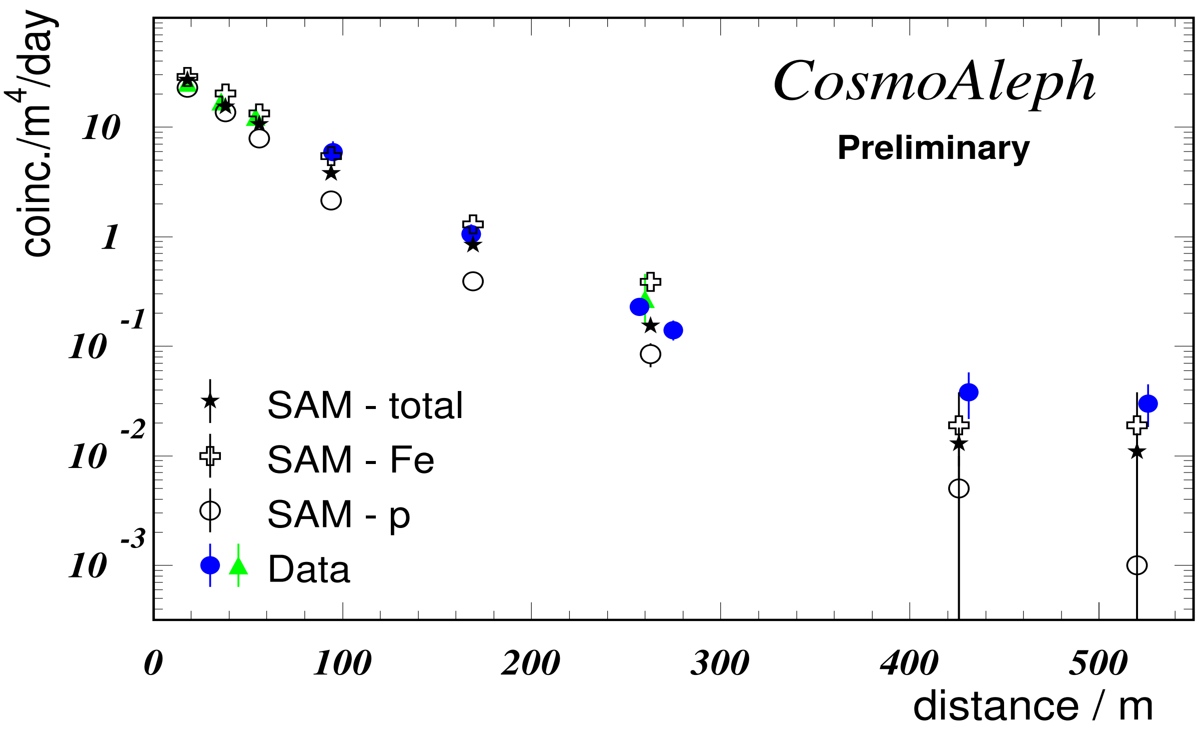

Figure 5.3. *Measured coincidence rates between two unit-detectors as function of their distance. Also shown is the prediction from a Monte Carlo simulation ("SAM"). SAM-total uses a primary particle composition of 37% p, 23% He, 14% CNO, 16% $NeSi$, 10% Fe independent of energy [38]. Fe and p were interpolated to this mixture via the Gaisser parametrisation [39].*

L3 has started a substantial cosmic ray activity, called L3C [3]. They have covered the top of their experiment with an additional layer of counters used to trigger on cosmic muons, independent of LEP data taking. OPAL is presently investigating a cosmic ray trigger by using their TOF counters. With the help of the GPS the LEP experiments, which are separated by about 6 km from each other, will search offline for coincidences. The proposed additional muon array of CosmoLEP, also equipped with GPS, will significantly increase the detector area for these measurements. We further propose to place a muon module with trigger-counters and GPS underground half way in-between ALEPH and L3, either in the hall or in the 700 m long tunnel of pit 3. The directional information from this muon array will help to identify the cosmic ray shower and will also shorten the coincidence interval since delays due to travel times can be corrected for. Later this year, 200 scintillation counters, each of 1 m^2, will become available from the HEGRA experiment. These counters could be placed around ALEPH and the new muon chamber array, to further study the structure of high-energy muon showers and to better identify the primary particle. Some of these counters could be placed underground between the two LEP experiments. We are further planning to use the GPS system to extend the coincidence measurements all over Europe by including the two HERA experiments H1 and ZEUS at DESY as well as the KASCADE experiment at Karlsruhe and perhaps others. H1 and ZEUS, already equipped with GPS time stamps, are triggering with 100% duty cycle on cosmic rays and are presently searching for cosmic coincidences between them.

6 Schedule and Milestones

The present phase of CosmoLEP may have to stop taking data with the end of LEP operation. This implies that the experiment should run as soon as possible in order to accumulate sufficient statistics. However, before running can commence, a variety of issues must be resolved.

As a result of various contacts with the ALEPH collaboration, the ALEPH steering committee has established a task force to evaluate the technical implications of a possible installation of track chambers in the ALEPH cavern. While the general outcome of the review was quite positive, they clearly requested that the safety division TIS assess the safety compliance of the CosmoLEP proposal. It is assumed that the same safety requirements which apply to ALEPH will also apply to CosmoLEP. Initial discussions with the TIS group have not revealed any insoluble safety problems and hence TIS is confident that there investigations in the coming months will have a satisfactory outcome. A summary of the first meeting with TIS is given in the appendix.

It is an understandable desire of ALEPH that all chambers, counters and electronics undergo final testing prior to installation in their underground cavern. The mechanical stability of the set-up has also to be demonstrated. These tests are presently under way in the former BEBC hall. After this milestone has been fulfilled (probably by the end of October) we will ask for permission to install the first two modules. We will gain some experience with these chambers in the early stage of the experiment. In parallel, the remaining chambers and counters will be tested with the goal that the complete set-up will be installed at the end of the year.

If the counters from the HEGRA experiment will be available in time we would like to install them in the neighbourhood of the new array in order to obtain further information about the shower size. Furthermore, it is thinkable that another small chamber array could be installed close to the pit 3, half way between ALEPH and L3, in a later stage of the experiment. During the year 2000 CosmoLEP proposes to run continuously and we will use any possible opportunity to take data together with the ALEPH detector. The GPS system, which is by now a standard equipment in the LEP tunnel, will be used for synchronization with the other LEP detectors.

7 Budget

The proposed experiment would have required a budget of probably more than 6 million Swiss Francs, if newly constructed. The use of existing detectors and electronics and also the infrastructure of CERN reduces these expenses dramatically. It is our understanding that CERN cannot invest substantial amount of much manpower into CosmoLEP. The manpower is therefore mainly supported by the collaborating institutes. However, some funds, in addition to the hardware, will be needed for subsistence allowances at CERN and for a project associate. We have estimated the required budget for the installation of the experiment and the run expenses up to the end of the year 2000 (see Tab. 7.1). This budget is in addition to the already granted exploitation allocation.

During the approval phase of the experiment the already started negotiations with the participating institutes have to be continued. We are confident that about 100.- kFS of the installation and consumption budget can be taken over by the collaborating institutes. However, one should not forget that these institutes have already contributed in advance via manpower and by supporting the analysis of the cosmic ray data of ALEPH and the present tests of the muon chambers.

Material budget:	
Mechanics, installation and gas system for the muon chambers	38. kFS
Detectors and installations for safety requirements, assuming that some material is available from TIS, fences	15. kFS
Cables, connectors etc	18. kFS
Repairs of the muon chambers and associated electronics, gas consumption in the test set-up	8. kFS
GPS systems with read-out and specialized electronics	22. kFS
Installation of the trigger counters: mechanics, repairs, cables	12. kFS
DAQ and data storage	18. kFS
Electronics pool rental	
1999	50. kFS
2000	80. kFS
Gas consumption	
1999	6. kFS
2000	14. kFS
Transport and installation of 200 HEGRA counters (year 2000) The estimation depends on the cost of transport, status of the counters and availability of cables usable at CERN	30. kFS
Total	311. kFS
Contribution from participating institutes (1999-2000)	100. kFS
Contribution from CERN (1999-2000)	211. kFS
Subsistence allowances for students and physicists (50% for eastern countries) and one project associate	
1999	32. kFS
2000	75. kFS
Summary:	
Total CERN contribution 1999	133. kFS
2000	185. kFS

Table 7.1. *The CosmoLEP budget for the years 1999 and 2000*

8 Outlook

During late April of this year, there was a dedicated 5 day ($.5 \cdot 10^6$ sec) cosmic ray run of the ALEPH detector. This run included the readout of the hadron calorimeter, increasing the sensitive area from the 16 m^2 of the TPC to 50 m^2. The data acquired during this special run was important in order to better understand the data previously taken with the LEP triggers, and has been a critical step in the design process for the present proposal.

A major goal of the present proposal is to study the spectacular highest multiplicity multi-muon events, which are not well reproduced by the Monte Carlo. It is gratifying that such events were seen during this short special run, including the event illustrated in Fig. 8.1.

The present proposal provides for a further 4-fold increase in the total area sensitive to muons. Running continuously during the year 2000, it will provide a sample of many hundreds of such events. The complete data set will be extremely rich, and will enable significant progress in understanding the composition of the cosmic ray primaries and possible anomalies in multi-particle production.

It is not a part of this proposal and out of the present financial range, but a large counter array, like EASTOP from Gran Sasso [40] or the KASCADE [4] array, on top of ALEPH at the ground level would give complementary information about the electromagnetic component of the showers which caused the muon bundles. Such an experiment is the dream of many cosmic ray physicists and could be constructed almost entirely from existing equipment [41].

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It is a pleasure for the CosmoLEP group to thank the ALEPH collaboration for the permission to use their LEP data for the cosmic ray studies and for the discussions about a possible installation in their underground cavern. We are grateful to the NOMAD collaboration which was so kind to give us on loan the read-out electronics for the muon chambers. We thank the Padua group for allowing us to use their trigger counters and related electronics. Without the Aachen muon chambers this proposal would not have been possible. Thanks for leaving the chambers to us. We thank the many people who contributed directly and indirectly to the project.

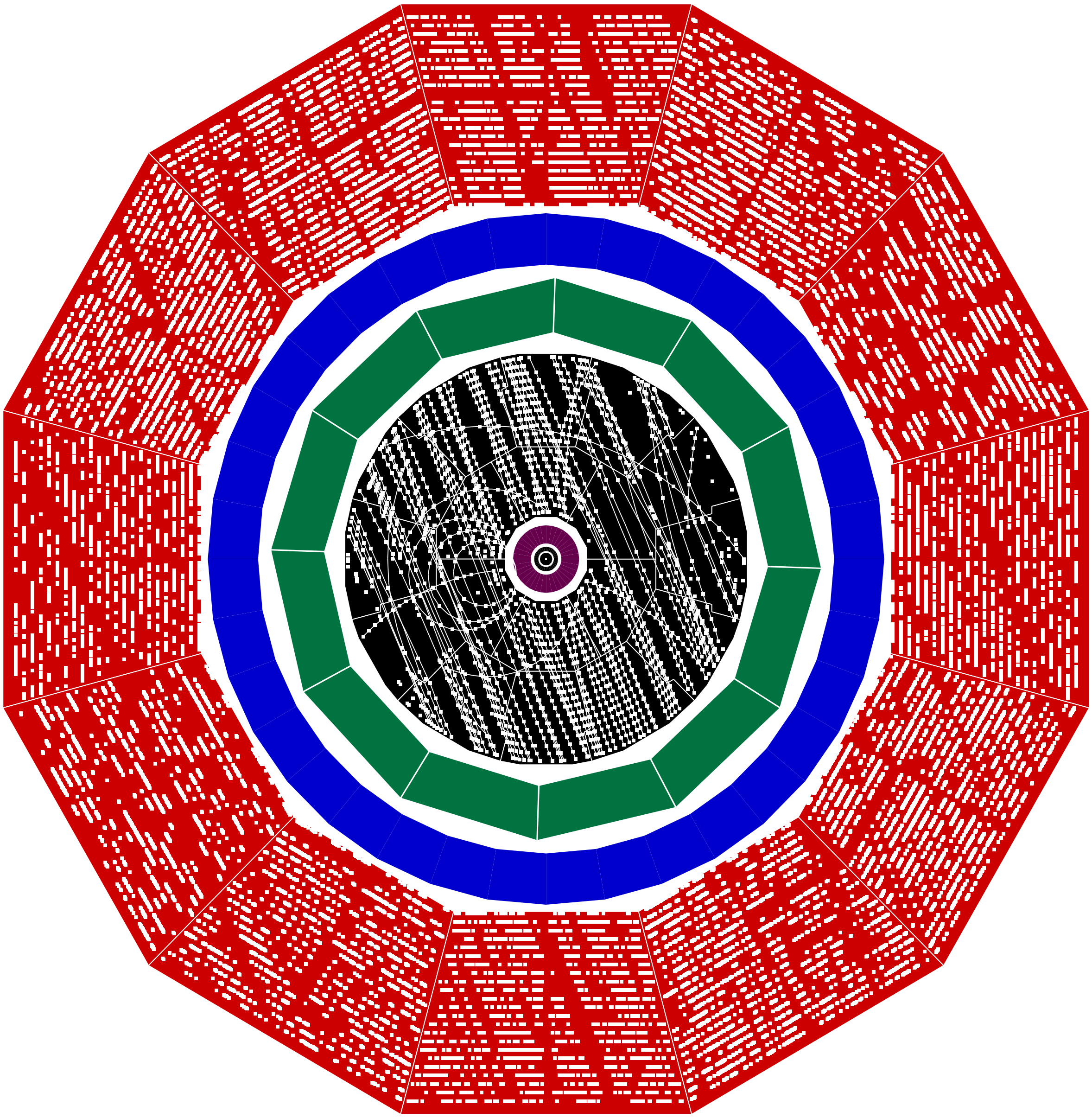

Figure 8.1. *High multiplicity event from a dedicated cosmic run with ALEPH*

A Safety Requirements

While CosmoLEP will run its detectors using a non-flammable gas mixture, a variety of safety considerations involved in running the muon array in the ALEPH underground cavern, which also contains the flammable gas of the ALEPH detectors, must be addressed.

The ALEPH steering committee has established a task force to evaluate the technical implications of the installation and running of the muon array in the ALEPH cavern. A list of the ALEPH safety concerns has been forwarded to us, and has been discussed in an initial meeting with TIS under the chairmanship of Dr. Weingarten/TIS. The relevant experts have expressed their belief that all safety considerations of CosmoLEP can be correctly addressed. They have given the following preliminary recommendations:

A GLIMOS for CosmoLEP should be appointed who reports to the Technical Coordinator/GLIMOS of ALEPH. In order to avoid safety problems due to the interference of different activities, the implications of the operation of CosmoLEP must be discussed with the safety coordinators.

The mechanical stability of the chamber set-up, particularly the structural stability in the presence of vertical acceleration during an earthquake, must be discussed with TIS-TE.

The fire safety of existing material (such as cables and plastics) must be checked with respect to conformity to current standards. In the case of a flammable gas leak in ALEPH, CosmoLEP power supplies must be automatically interrupted. In order to avoid fire in the racks or close to the chambers, an early smoke detection system must be considered and an automatic extinguishing of the fire must be foreseen.

In order to ensure gas safety, the risk of asphyxiation in the event of a gas leak must be evaluated and the position of oxygen deficiency sensors must be defined. A test by TIS should be made with the sensors available in TIS-GS-GC. In case of an Ar/CO^2 gas leak the supply must be automatically closed.

The compatibility of the heat dissipation in the CosmoLEP electronics with the existing ventilation system of the cavern must be assessed. A cooling system based on water heat exchangers shall evacuate the dissipated heat to the surface buildings.

In order to ensure the safety of visitors, a reduction of the number of visitors per group may be envisaged. The access and evacuation of visitors is impeded by the passages to ALEPH which will become narrower after CosmoLEP installation.

Finally, the level 3 alarms and corrective actions in case of such an alarm must be defined in accordance with the ALEPH alarm system.

In principle, TIS believes that all safety aspects can be solved and they will further assess the safety compliance of the CosmoLEP proposal, bearing in mind that a final answer has to be given before the approval of CosmoLEP.

References

[1] O.C. Allkofer, K. Eggert, P. Erhard et al. *"The UA1 detector as a possible cosmic ray device"*, Proc. 17th Int. Cosmic Ray Conf., Paris, **10** (1981) 401

[2] H. Wachsmuth, *"Proposal to search for Cosmic Ray coincidences in the LEP detectors "* draft, 16.Dec.1993 (CosmoLEP-note 94.000)
A. Ball, G. Bonvicini,C. Grupen, et al. CERN/LEPC 94-10, LEPC/M 109 (1994)

[3] P. Le Coultre, L3C collaboration, Proceedings of the 25th Int. Cosmic Ray Conf., Durban, South Africa, Vol. 7, p. 305.
"L3+Cosmics Experiment" in "Experiments at CERN in 1998" (Grey book), p.369.

[4] H.O. Klages for the KASCADE Collaboration, *Proc. 25th Int. Cosmic Ray Conference*, Durban (1997), Vol.8, 297

[5] B. Wiebel-Sooth, *"Measurement of all particle energy spectrum and chemical composition of cosmic rays with the HEGRA detector"* Dissertation, University Wuppertal, Sept 1998 WUB-DIS-98-9

[6] J. Hörandel for the KASCADE Collaboration, Proceedings of the 16th European Cosmic Ray Symposium, July 20-24, 1998, Dept. Fisica, Universidad de Alcala, Spain (ed: J. Medina) page 579.

[7] Useful reviews include: K. Rajagopal, in *Quark-Gluon Plasma 2*, edited by R. Hwa, World Scientific, Singapore, (1995), p. 484; J-P. Blaizot and A. Krzywicki, Acta. Phys. Polon. B **27**, 1687 (1996); K. Ragjagopal, hep-ph/9703258, talk at the International Workshop on QCD Phase Transitions, January 1997, Hirschegg, Austria; J.D. Bjorken, in *Proceedings of the 1997 Zakopane School*, hep-ph/9712434.

[8] J. J. Lord and J. Iwai, Paper 515, presented at the International Conference on High Energy Physics, Dallas (1992); H. Wilczynski et al., Proceedings of the XXIV International Cosmic Ray Conference, HE Sessions, Rome (1995), Vol.1, p.1.

[9] E.V. Bugaev et al., Phys. Rev. D **58**,(1998) 1

[10] MACRO Collaboration, M. Ambrosio *et al.*, Phys. Rev. D **52**,(1995) 3793.

[11] SOUDAN Collaboration, Internal Report No. PDK-435, 1990 (unpublished).

[12] S. M. Kasahara, Ph. D. thesis, University of Minnesota, 1995.

[13] C. Castagnoli and O. Saavedra, Nuovo Cimento C **9**, 111 (1986).

[14] NUSEX Collaboration, M. Aglietta *et al.*, in *Proceedings of the Topical Seminar "Astrophysics and Particle Physics"*, San Miniato, Italy, 1989, edited by G. Castellini *et al.* [Nucl. Phys. B (Proc. Suppl.) **14B** (1990) 193].

[15] N. Ito (for the KGF Collaboration), in *Proceedings of the International Symposium on Underground Physics Experiment*, Tokyo, Japan, 1990, edited by K. Nakamura (ICRR, Tokyo, 1990), p. 101.

[16] Yu. M. Andreyev, V. I. Gurentsov, and I. M. Kogai, in *Proceedings of the 20th International Cosmic Ray Conference*, Moscow, USSR, August 2 – 15, 1987, edited by V. A. Kozyarivsky *et al.* (Nauka, Moscow, 1987), Vol. **6**, p. 200.

[17] Yu. M. Andreyev, A. E. Chudakov, V. I. Gurentsov, and I. M. Kogai, in *Proceedings of the 21st International Cosmic Ray Conference*, Adelaide, Australia, January 6 – 19, 1990, edited by R. J. Protheroe (Department of Physics and Mathematical Physics, University of Adelaide, Northfield, South Australia, 1990), Vol. **9**, p. 301; Yu. M. Andreyev (private communication).

[18] LVD Collaboration, M. Aglietta *et al.*, Astropart. Phys. **3**, 311 (1995).

[19] Fréjus Collaboration, Ch. Berger *et al.*, Phys. Rev. D **40**, 2163 (1989); Z. Phys. C – Particles and Fields **48**, 221 (1990).

[20] Fréjus Collaboration, W. Rhode *et al.*, Astropart. Phys. **4**, 217 (1996).
[21] P.L. Biermann, T.K. Gaisser, T. Stanev Phys. Rev. D **51** (1995) 3450.
[22] T. Stanev, P.L. Biermann, J. Lloyd-Evans, J.P. Rachen, A.A. Watson Phys. Rev. Lett.**75** (1995) 3056.
[23] T.C. Weekes Space Sci. Rev. **59** (1992) 315.
[24] F. Halzen, T. Stanev, G.B. Yodh MADPH 96-948, and astro-ph/9608201 and Phys. Rev. D **55** (1997) 4475.
[25] F. Halzen, T. Stanev MADPH 95-901, astro-ph/9507362.
[26] P. V. Ramanamurthy, A. W. Wolfendale *Gamma-ray Astronomy* Cambridge Astrophysics Series 1993
[27] M. F. Cawley, T. C. Weekes, *Astron. Astrophys.* **133** (1984), 80
[28] A. Borione, C.E. Couvault, F.W. Cronin et al. NIM **A 346** (1994) 329
F.W. Cronin, B.E. Fick, K.G. Gibbs et al. Phys. Rev. **D45** (1992) 4385.
[29] D. Decamp et al., ALEPH Collaboration, NIM A **294** (1990) 121
[30] D. Heck et al., Report **FZKA 6019** (1998), Forschungszentrum Karlsruhe
J. Knapp, D. Heck, G. Schatz, Report **FZKA 5828** (1996), Forschungszentrum Karlsruhe
[31] K. Eggert, Th. Ehlert, H. Faissner et al., NIM **176** (1980) 217
[32] S.Barwick et al., J.Phys.G:Nucl.Part.Phys. **18** (1992) 225
[33] T. Kitamura, S. Ohava, T. Kouishi et al.,*Ast. Part. Phys.* **6** (1997) 279
[34] O. Carrel, M. Martin, Phys. Lett. B **325** (1994) 526
[35] CERN/DG/ Research Board 94-216, Minutes 118 (5 October 1994), LEPC/94-14.
[36] A.-S.Müller, Nucl.Phys. B (Proc.Suppl.) **52** (1997) 261, H.Wachsmuth, Proc. of 25th International Cosmic Ray Conf., 1997, Vol. 7, p. and Proc.of Vulcano Workshop 1998, May 24-30, Vulcano, Italy, to be published and M.Schmelling, Finland workshop 1999
[37] A.-S.Müller and M. Schmelling, in preparation.
[38] J. Kempa, private communication.
[39] T. Gaisser, *Cosmic rays and Particle Physics*, Cambridge 1990 and Refs therein.
[40] see e.g.: NIM **A277** (1989) 23
[41] Such a view was strongly expressed by many of the participants in the First Arctic Workshop on Cosmic Ray Muons held in Sodankylä, Finland, April 24-29, 1999. The program, including scanned images of the speakers' transparencies, can be found at http://www.cern.ch/CosmoLep/conference/welcome.html