s t udents
a g 2005
e s infn-lnf

14 – 30 June 2005 summer students stage (INFN-LNF)

A complete Data Acquisition system with an e.m. calorimeter for cosmic rays and π^0 mesons study

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1) Cosmic rays

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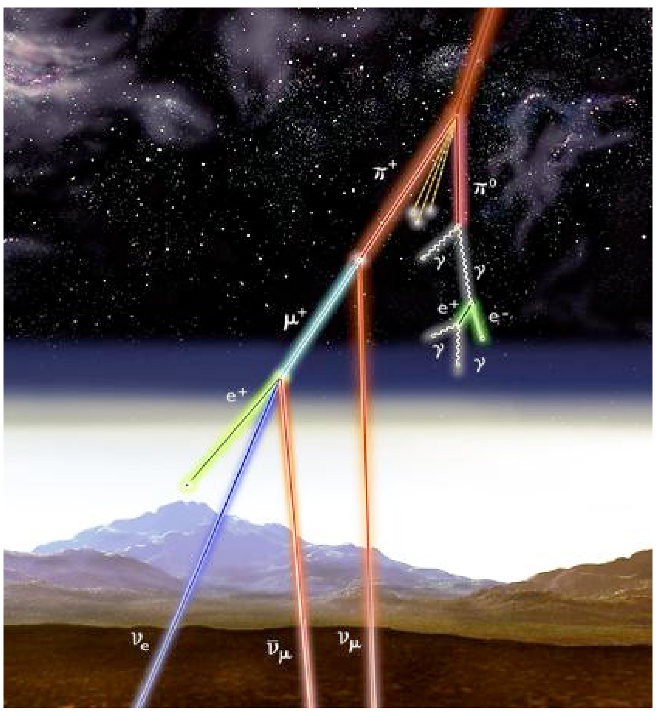
Abstract

The purpose of our work was to realize an acquisition system (DAQ) to analyze cosmic rays signals reconstructed by an electromagnetic calorimeter composed by lead foils and scintillator fibers. By using photomultipliers and logic modules, a study on the high voltage operating points has been performed.

After this, data from the Hermes e.m. calorimeter have been used to identify and study the particle π^0.

Cosmic rays



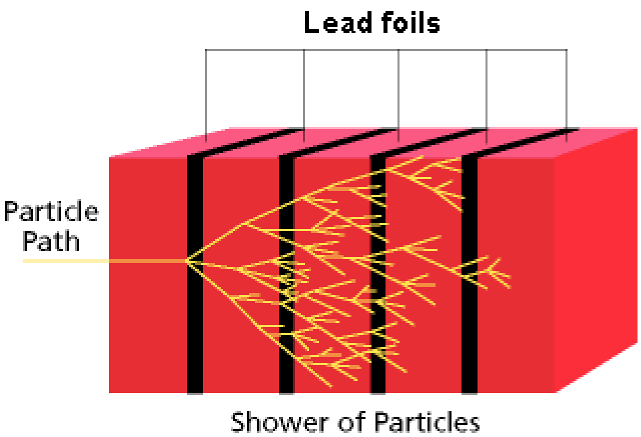
The cosmic rays, that as a mysterious rain coming from the space invests the earth, were the first source of elementary particles to be studied.

They allowed collecting information on the nature of the subatomic world before particle accelerators were invented. The exact origin of the cosmic rays is uncertain, even if it seems that they are produced from outbreaks of supernovae or reactions that happen in stars, such to accelerate particles to highest energies and to diffuse them in all the directions in the space. The cosmic rays that hit the external layer of the atmosphere are said primary cosmic beams and are mainly protons of high energy. In their travel towards the land surface, they collide with atoms in the air, creating new particles and antiparticles that constitute the secondary cosmic rays. This phenomenon is the origin of the cosmic rain that invests the earth. From its analysis, in the 30's the antimatter positron, the pion and the muon ,elementary particles, were first discovered. Inside the cosmic rain there are also neutrinos.

Data acquisition system:

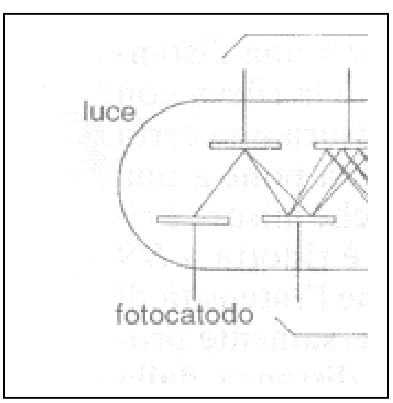
Calorimeter

The kind of calorimeter we used is an electromagnetic sampling calorimeter, which is optimized to reveal electromagnetic showers, formed by photons, electrons and positrons.

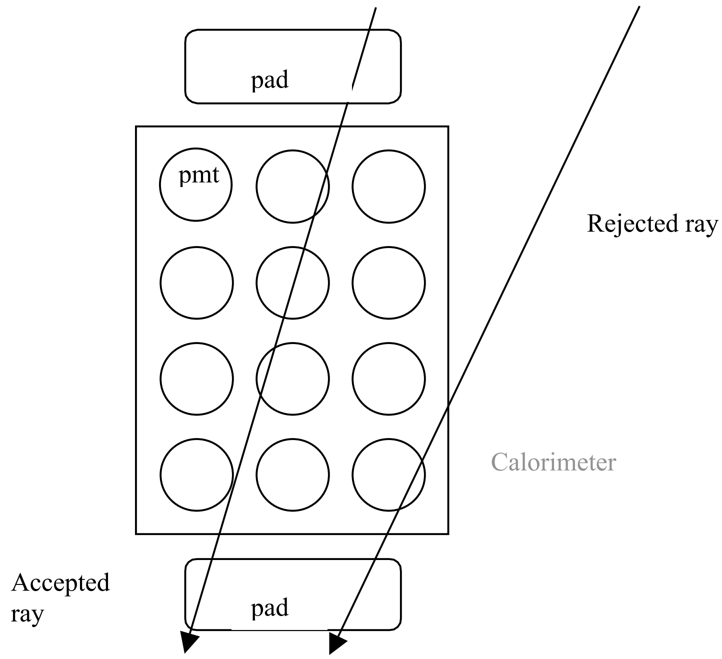


The calorimeter is composed by a sequence of passive layer and an active one. The passive layer is aimed to stop the particle and to absorb its energy. It also starts the electromagnetic shower. In this situation the passive layer is composed by lead foils. The active layer instead is aimed to reconstruct the particle's track without influencing it. In our calorimeter we used scintillating fibers. It is composed by four modules of three groups of fibers and lead, each ending on a photomultiplier (PMT). When a particle hits the calorimeter it creates an electromagnetic shower. From the scintillation process due to the fibers, the generated photons travel through the scintillating fibers and reach the photomultipliers.

The photomultiplier allows amplifying a weak signal transforming it into an electric signal. It is based on the photoelectric effect. When a photon reaches the photocathode, electrons are created because of the photoelectric effect, and are brought into an electric field on a series of dynodes. On each dynode the electrons multiply because of a thermoelectric effect with a shower process.



There are also two scintillating pads, one above and one below the calorimeter to perform the coincidence trigger. They are used to select only the particles that passed in a definite solid angle.



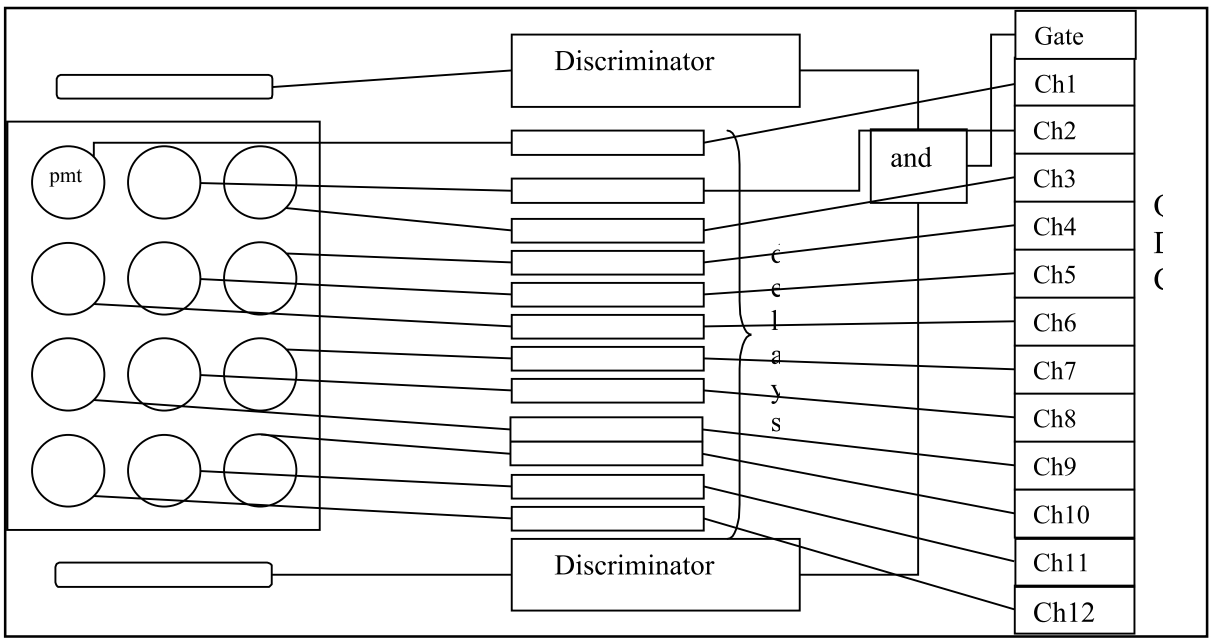
Logic Units

To collect and convert the analogic signal coming from the PMTs we have assembled an acquisition system with the following logic units:

- 2 DISCRIMINATORS: they are circuits which turn every input signal in a formed output signal that is a signal which has fixed amplitude and variable duration.
- 1 AND-LOGIC: it is a circuit that gives an output only when the entry signals come at the same time. We connected the discriminators' signals to the logic because we needed to read only the signals that hit at the same time both of the pads, one the calorimeter, of course.
- 1 GATE: it is a circuit that, when an entry signal is sent, gives an output signal of variable duration. We used it to make the acquisition system sensitive only for a determined time range after the revelation of an event. Our gate was included in the QDC.
- 12 DUAL DELAYS: creating the gate, a delay has appeared on the pads' signal, so it did not coincide with the PMTs signals. We added a specific

delay on each PMT signal so that they were all syncronized to the pad's one.

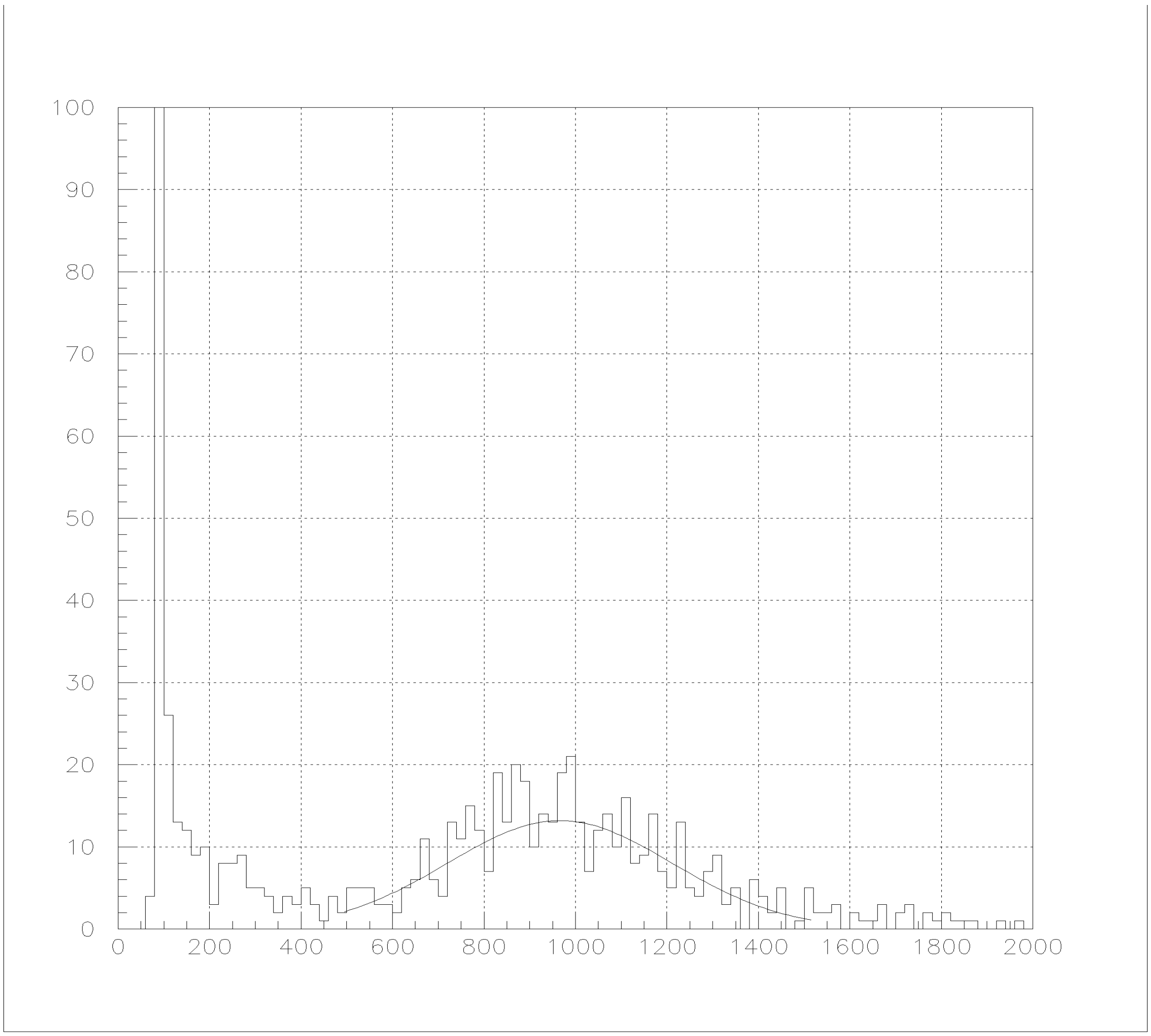
1 QDC: it converted our signals to digital ones and sent them to the computer for the storing of the data.



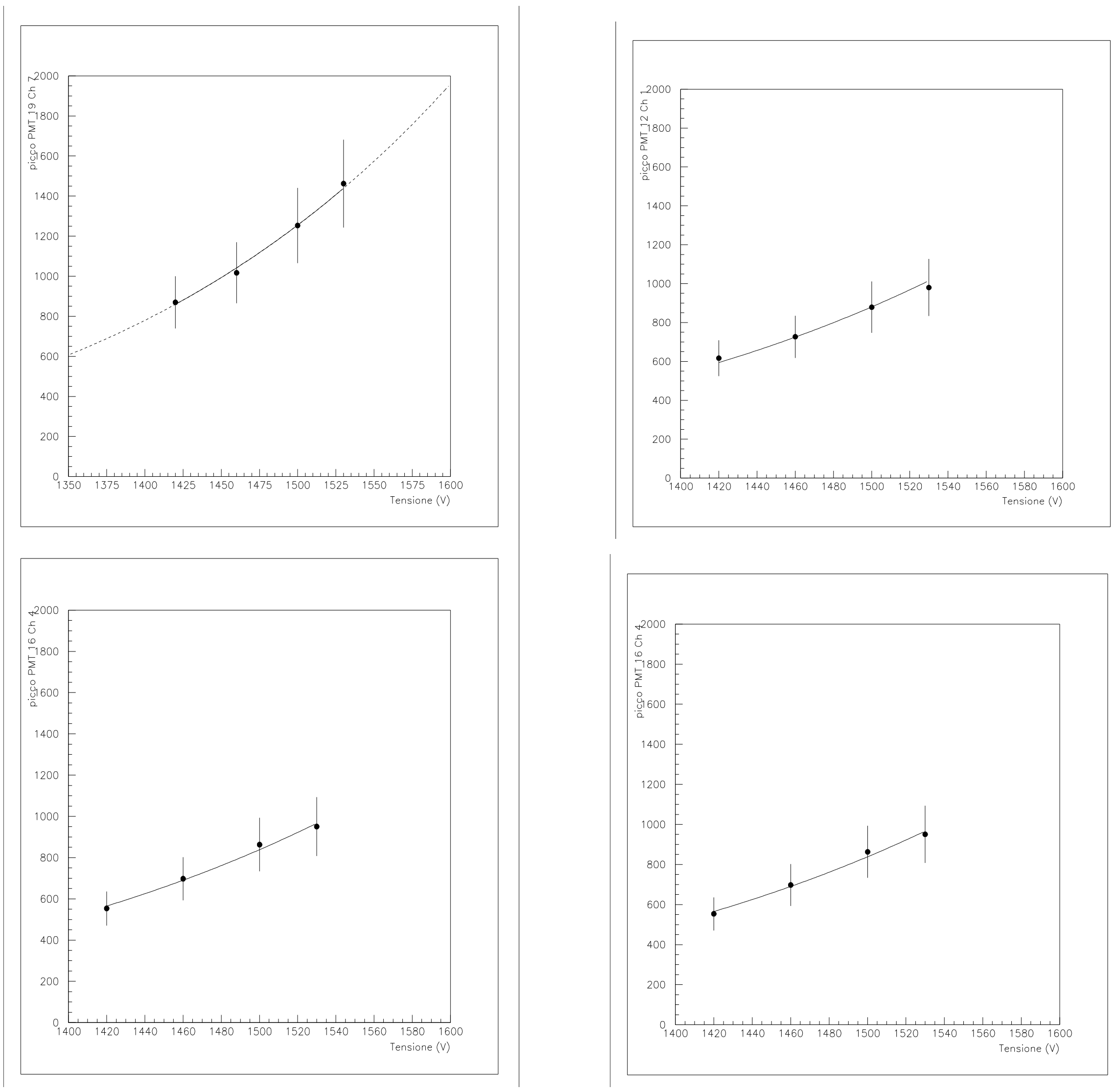
Calibration curves

For data acquisition we used the LabView framework. We executed different runs, setting the PMTs' high voltage to various values (1540V, 1500V, 1460V, 1420V).

To analyze the data we used the program Paw++, which allowed us to make the spectrum of each PMT's revelations. Then we made the fit of the graphics in order to get the mean values of the gain. Making the plot of the mean value of the gain (see plot "Collected data") vs PMT's high voltage for each channel, we were able to see the calibration curve for each photomultiplier tube



Collected data (Ch 2)



PMT peak vs Voltage

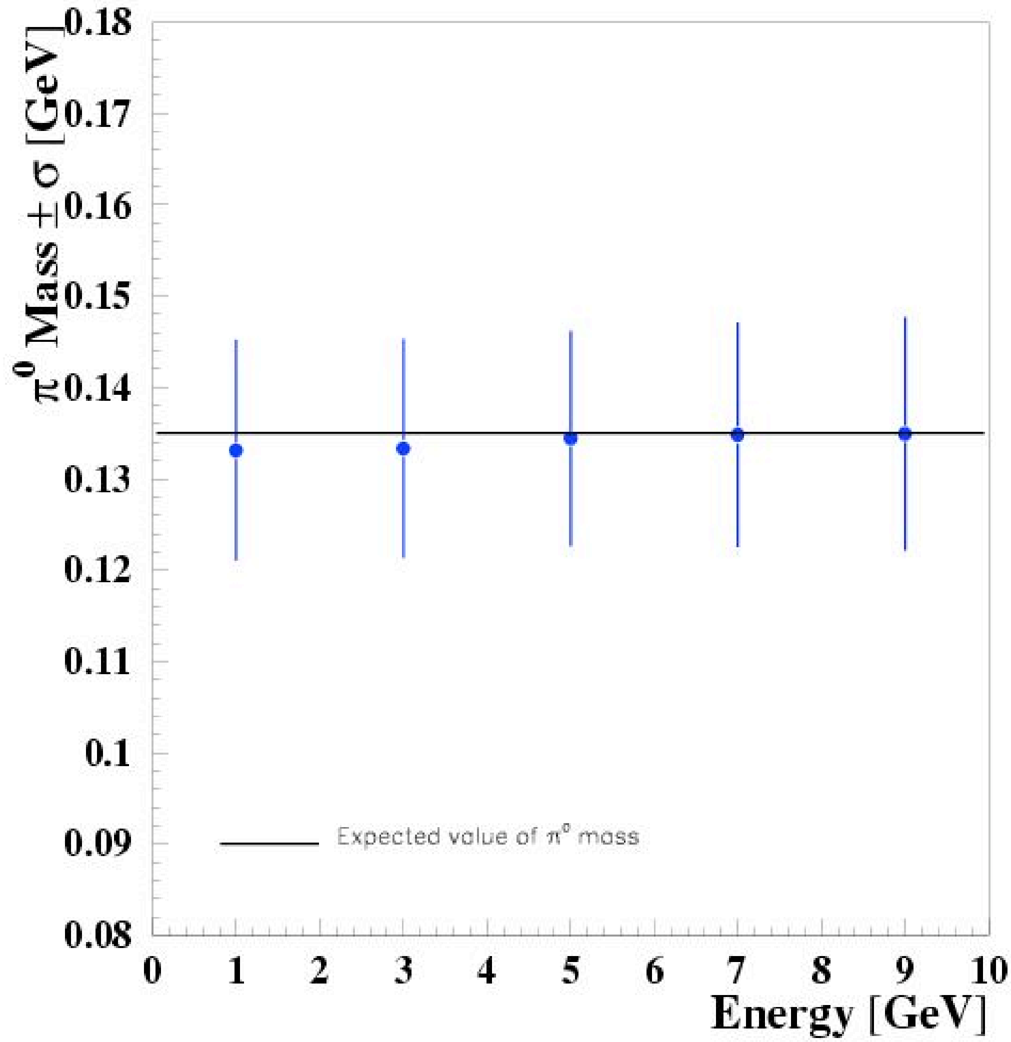
π^0 mass studies

The particle π^0 is a meson formed by a mix of u and d quarks $\frac{1}{\sqrt{2}}\left(u\bar{u}+d\bar{d}\right)$. It is not a stable particle and decays in two photons in the 98.8% of the time. Its life time is about 10^{-17} seconds. Identifying the photons by an electromagnetic calorimeter we can reconstruct the particle π^0. In fact, considering the energy and the momentum from simple quadrimomentum conservation laws, it is possible to have the π^0 mass:

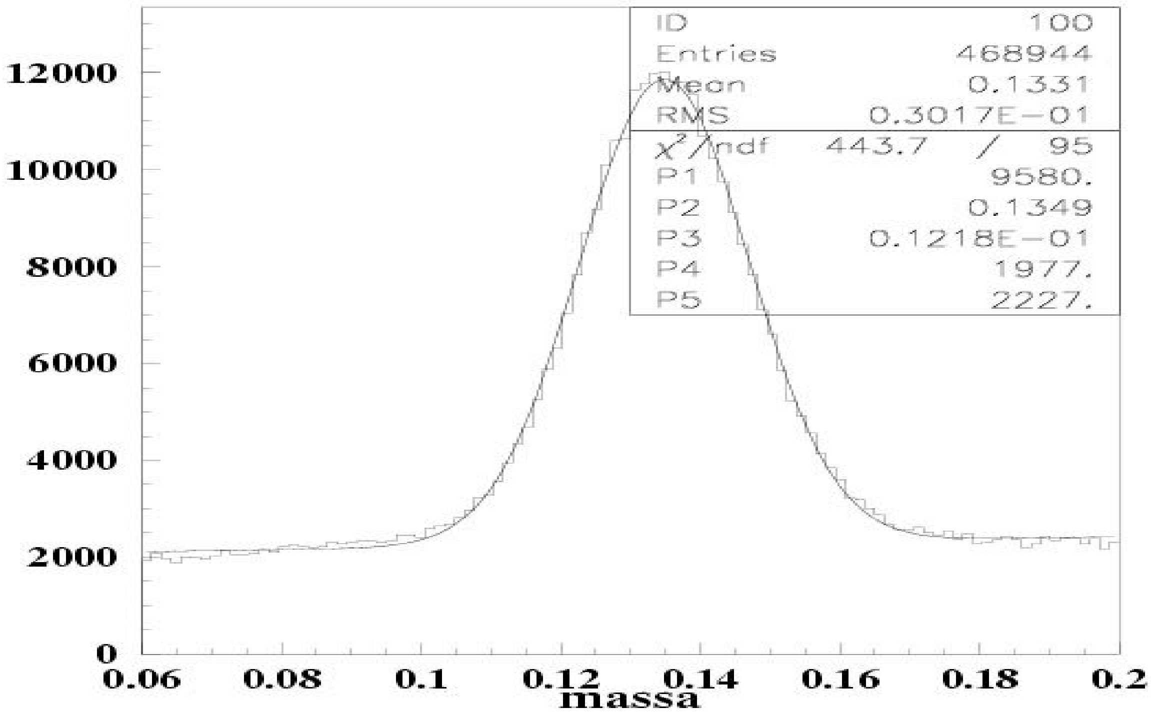
$$\mathbf{E^2 = p^2 + m^2}$$

Using files collected by the Hermes experiment in data taking at the accelerator HERA (Desy laboratory in Hamburg), we have done a histogram for the reconstructed invariant mass values. To obtain the mean value of the distribution we have done the fit which is resulted a superposition of a gaussian curve and a first order polynomial. The mean value of the histogram is the mass of the particle π^0. The measured result was 0.135 GeV, which coincides with the expected value reported in the Particle Data Book.

We have done various spectra considering different π^0 minimum energies (1; 3; 5; 7; 9 GeV). Considering for each spectrum the mean values it is possible to make a graphic which shows the variation of the mass as a function of the π^0 minimum energy. The result is a constant value. This means that the reconstructed mass does not depends on the energy of the particle.



In the invariant mass spectrum we can observe two areas: the signal, coming from a real decay of the π^0 , and the background, coming from uncorrelated photons. These areas are defined by the gaussian curve and the first order polynomial respectively. We can observe, in the different spectra, that increasing the π^0 energy the background decreases because the uncorrelated weak photons are cut away.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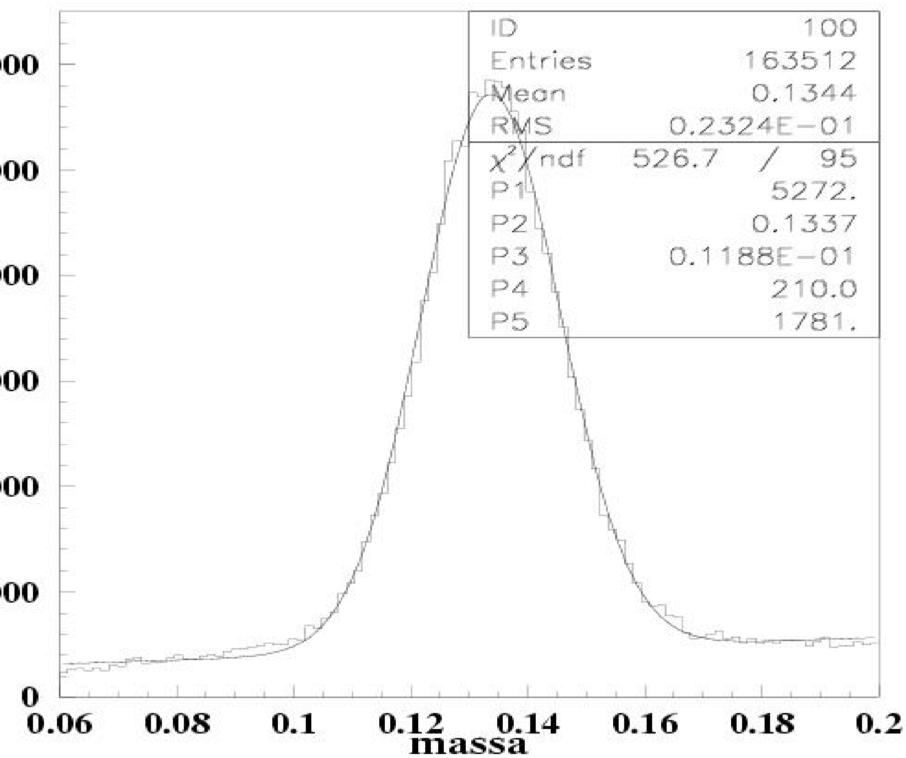
Entries 468944
Mean 0.1331
RMS 0.3017E-01
χ^2/ndf 443.7 / 95
P1 9580.
P2 0.1349
P3 0.1218E-01
P4 1977.
P5 2227.
12000
10000
8000
6000
4000
2000
0
0.06 0.08 0.1 0.12 0.14 0.16 0.18 0.2
massa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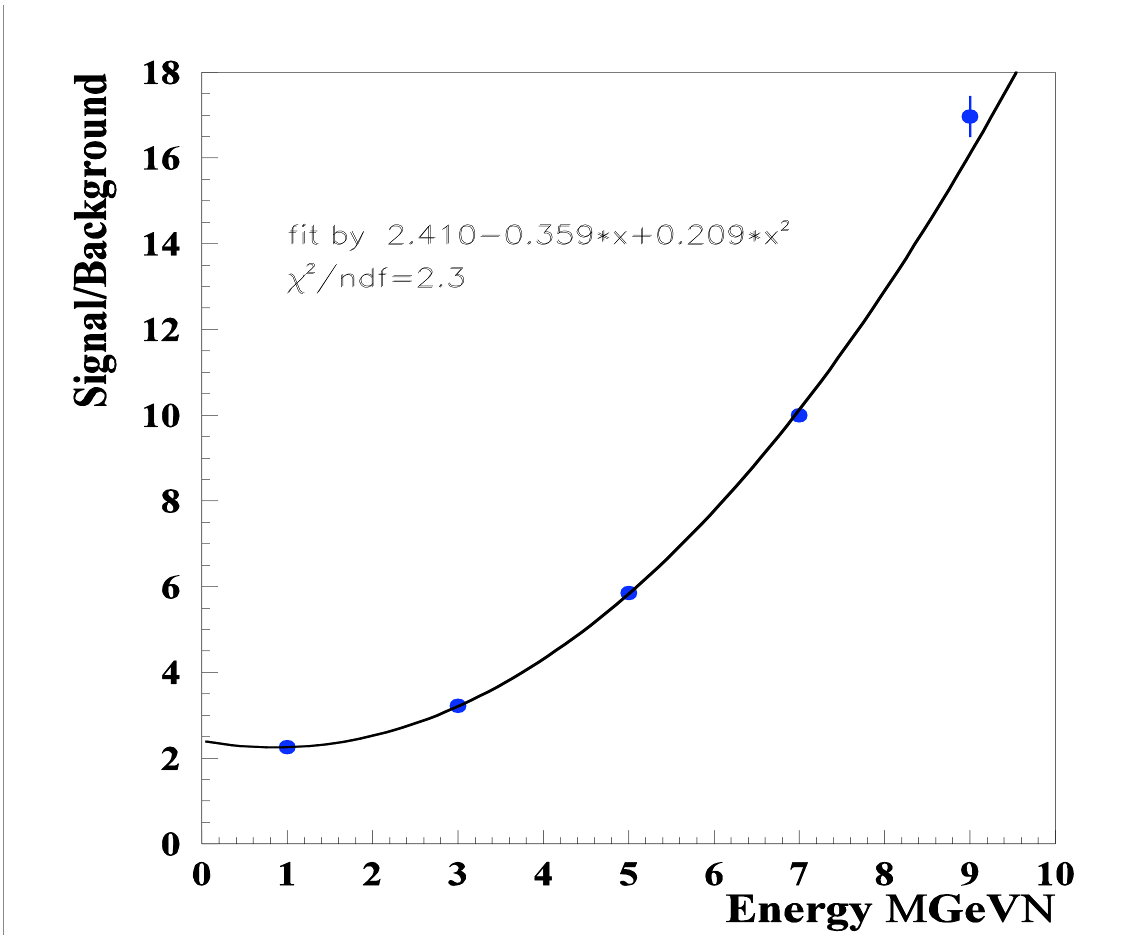
Mean 0.1344
RMS 0.2324E-01
χ^2/ndf 526.7 / 95
P1 5272.
P2 0.1337
P3 0.1188E-01
P4 210.0
P5 1781.
6000
5000
4000
3000
2000
1000
0
0.06 0.08 0.1 0.12 0.14 0.16 0.18 0.2
massa

For each spectrum we have calculated the ratio between the signal’s area and the background one. Then we have plotted this ratio as a function of the minimum energy of π^0 . To find the interpolating curve we calculated the χ^2 values for an exponential curve and a second order polynomial. The best fit resulted to be the second order polynomial, as the χ^2 value was 2.3, while for the exponential one it was 123.



Conclusions

We have reconstructed cosmic particles by a working electromagnetic calorimeter made of lead layers and scintillation fibers. We have created a data acquisition system that converted the analog signal coming from the calorimeter to a digital one storing all the data on file. Our system also selected only the particles that passed in a fixed solid angle by a coincidence method.
We have analyzed the data we acquired within a Linux operative system, using Paw++ and creating the calibration curve for each of the 12 channels.
In order to perform a study on a calorimeter working in a real experiment, we have reconstructed the π^0 particle invariant mass, analyzing data coming from the Hermes experiment. Our studies were concentrated on the relation between the π^0 mass and the its energy, observing that the mass is invariant and does not depend on the energy. We studied also the ratio signal/background in the mass spectrum as a function of the minimum energy of the π^0 . From this study it was clear that the uncorrelated photon pairs (background) are present mainly at low energy. At high energy the π^0 signal strongly dominates even if also the number of events is reduced.