Summer stage 2003-LNF

STUDY ON PARTICLES REVEALED THROUGH SCINTILLATORS AND CERENKOV COUNTERS

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1. EXPERIENCE PURPOSE AND METHODOLOGY

The work performed during the three weeks of this stage was focused on two steps. The first one consists in setting up a simple data acquisition system for the collection of cosmic ray signals. The second step was concentrated on the analysis for identifying and reconstructing a subnuclear particle, generated in accelerator collisions.

2.COSMIC RAYS

According to the Standard Model, matter is made of 12 quarks and 12 leptons (considering both matter and antimatter). Elementary particles only exist when the energy conditions allow the creation of their mass. Some of them are produced by the interaction of high energy particles coming from the outer space with Earth's atmosphere: they are the cosmic rays [1].
Some of them get to Earth as protons, _ particles, electrons, muons and heavy nucleons; others interact with the atmospheric atoms creating secondary particles as π mesons (pions), which exist in three states of charge $\pi^0(\frac{1}{\sqrt{2}}$ (uu- + dd-)) π^+(ud-) π^- (du-). In general due to the weak or the electromagnetic force, most of the particles decay in others. It's worth to notice that when particles have a speed next to that of light, time expands, so decay occurs in longer times, allowing us to reveal and study them easier.
In the last part of this work we will concentrate on the π^0 which decays in two _ photons because of electromagnetic force in a time of about $8*10^{-17}$ sec , Fig. 1.
Like for the other particle identification, revelation occurs through instruments which exploit the particles' interactions with other atoms.

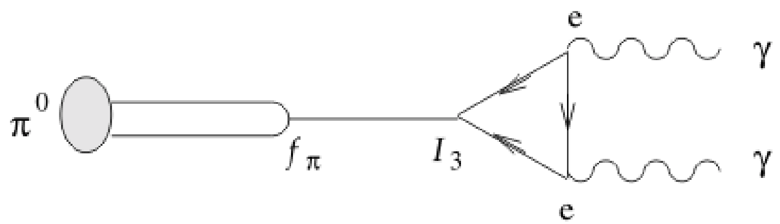


Fig.1: *π^0 decay in two _photons.*

3.DETECTORS

Charged and neutral particle detection

The purpose of the detectors is to locate and separate a particle in time and space and to measure its mass observing its interactions and decay products. Apart from their operation, detectors depend on the fact that when a charged or neutral particle traverses matter, it releases part of its energy to the medium, thanks mainly to the electromagnetic or strong interactions with the atoms, producing in the medium either atom excitement, with subsequent photon emission, or ionization which allows to check the particle's passage. Neutral particles instead must produce secondary charged particles to be revealed. These secondary particles lose energy ionizing and exciting allowing us to reveal the initial neutral particles [2] [3].

There are different kinds of detectors: in our experience we used both a _erenkov and a scintillator counter.

The Scintillator

We define a scintillator to be any material that produces a pulse of light shortly after the passage of a particle, which interacts with the electromagnetic field of the material's atoms through an exchange of photons [4]. Therefore we have the excitement of an electron which can lead to two different situations:

1)the electron passes to the upper energetic level and going back to his level it releases a photon.
2)the energy transfered to the electron is such to allow the emission of the electron and in this case signal consists in the electron itself.

The _erenkov counter

If a charged particle traverses the medium with a speed slower than c (light speed in that medium), molecules polarize and depolarize without photon release because electromagnetic signals from the depolarization interfere in a destructive way.

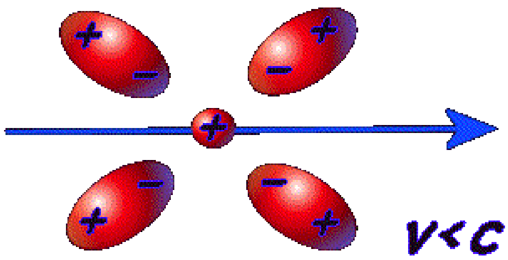


Fig.2: *Symmetric polarization.*

When particle's speed is faster than c, molecules depolarize after the particle's passage in an asymmetrical way and an electromagnetic wave is emitted.

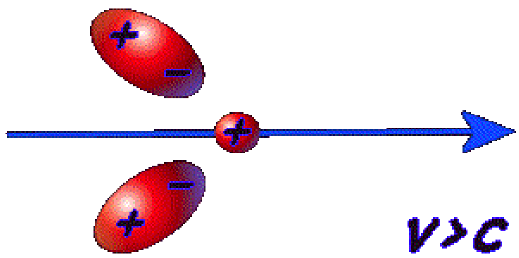


Fig.3: *Asymmetric polarization.*

This is called the _erenkov effect. Lead-glass ones are widely used for the detection of photons because in a dense medium it's easier both to exceed speed of light and easily absorb all the particle's energy [4].

Photomultiplier tube

By the above mechanism the produced light consists in only few photons. These must be propagated through light guides and directed onto the face of photomutiplier tubes (PMT) which converse the photons and amplify them into an electrical pulse. The emitted photoelectrons are accelerated and focused onto the dynodes of the tube: the overall amplification of the tube is of the order of 10^7. The exact amplification depends critically on the high voltage applied between the dynodes.
The pulse emitted by the photomultipier tube goes through an electronic equipment and finally gets to a computer which converts it into numerical data.

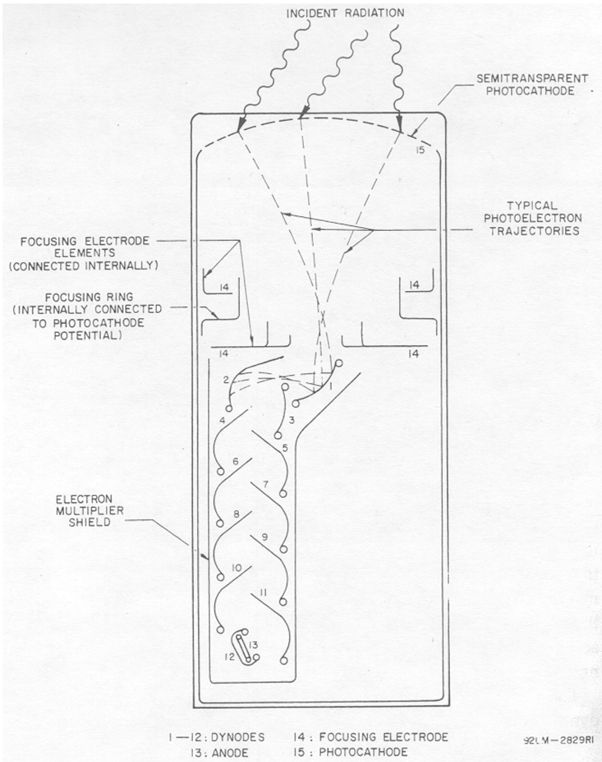


Fig. 4: *Photomultiplier tube (PMT).*

Electronic equipment

We used the electronic equipment shown in Fig. 5 both for the detection of cosmic rays through two scintillators and of light emitted by a led installed on a lead glass _erenkov counter.
By the lead glass we measured the constant signal from the led; through the scintillators we have revealed the passage of cosmic rays tuning the threshold to eliminate as much background as possible. It is due to the fact that the photomultiplier, working at high voltage, emits itself photons and electrons

unconnected to the passage of particles.

Moreover we make the coincidence between the two signals coming from the scintillators to eliminate the background: in fact, since the two scintillators are separated, they have different background so it is nearly impossible to have at the same time a false signal from both the detectors.

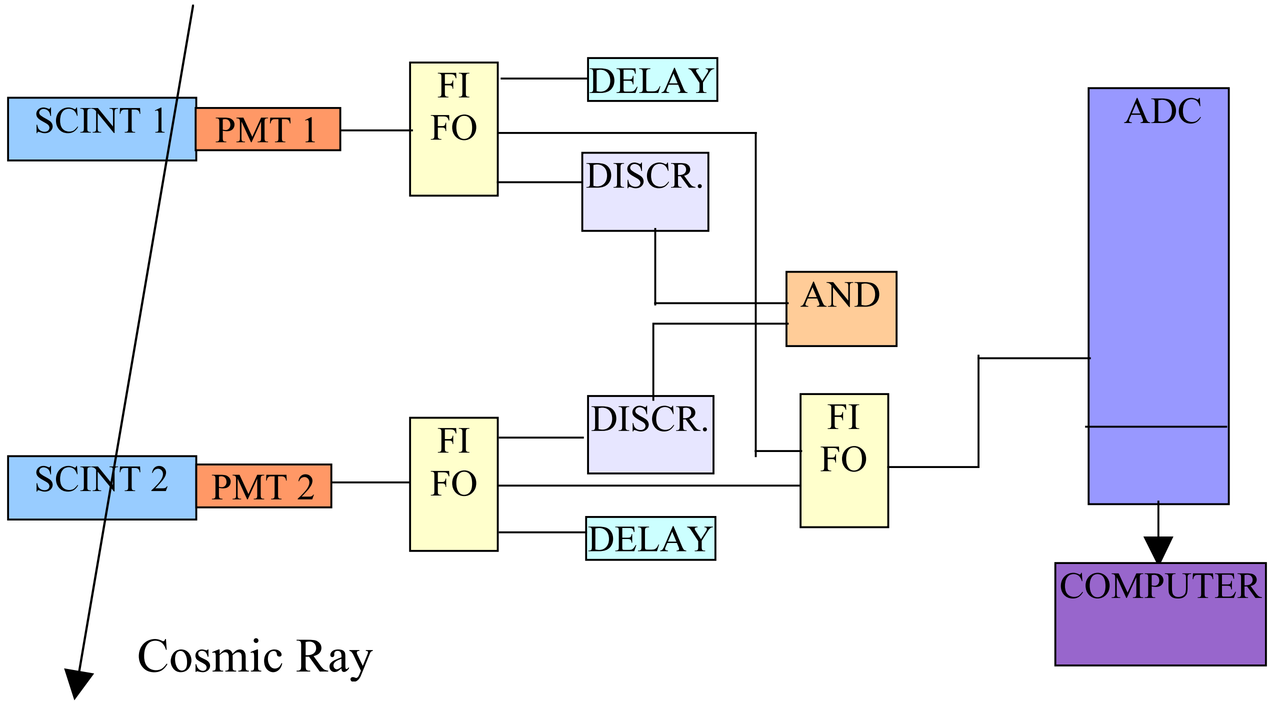


Fig. 5: *Data acquisition chain.*

Data acquisition element description

FANIN / FANOUT: The signal from the photomultiplier tube goes to the fanin/fanout circuit which has as output two equal signals to the discriminator and to the delays.
DISCRIMINATORS: They are circuits which supply a formed output signal (with an established width and a variable length) when we have a non-formed input signal (higher than a fixed value, the threshold).
DELAYS: They do in manner that the signal from the fanin/fanout and from the discriminator are on time.
GATE: It receives the signal from the discriminator and transmits it to the computer.
ADC: It converts the analogical signal to a digital one and sends it to the tcomputer.
AND: It has N input channels and supplies an output signal when the input signals arrive simultaneously.

Analysis of the acquired data

In the graphic below we can see the different distribution of the events, using two threshold values (30 and 61 mv). With a higher threshold we can notice a reduction of the background and a clearer signal from the cosmic rays:

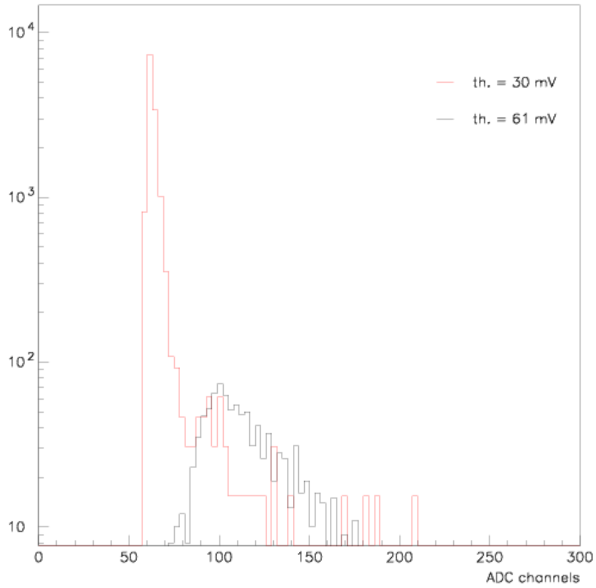


Fig. 6: *Event distribution as a function of the thresholds.*

In Fig.7 we have a plot of the two separate scintillators and that of their sum, obtained making their coincidence. In this way the background has been further reduced, recording nearly the only signals deriving from a particle. The peak of the sum plot is as wide as the sum of the two scintillators', but, as the number of events is the same, that of the high of the peak is the half:

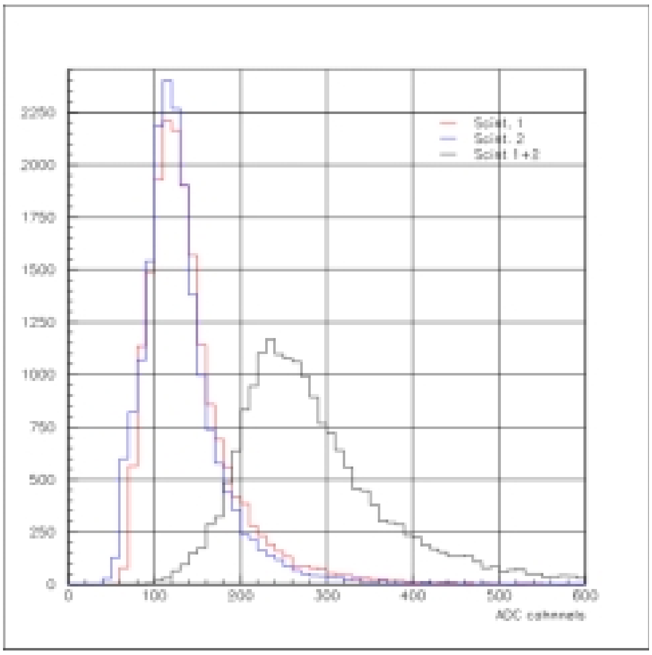


Fig. 7: *Plot of the two separate scintillator and of their sum.*

Thanks to the energy loss tables, which according to the kind of particle (in this case muons) and the scintillator's material give us the value of the deposited energy, and knowing the thickness of our scintillators we are able to define a calibration polynomial (Fig.7). In the table below we record the peaks positions, the ADC pedestals and the lost energy:

SCINTILLATOR	**PEAK**	**PEDESTAL**	**PEAK-PEDESTAL**	**ERROR**	**LOST ENERGY**
1	115	27	88	± 5 Ch	
2	114	19	95	± 5 Ch	
1&2 AVERAGE	114.5			± 5 Ch	1.3 MeV
1+2	236	22	214	± 5 Ch	2.6 MeV

The values in the last column have been obtained multiplying dE/dx (1.7 MeV*g^{-1}*cm^2) with the scintillator's thickness (0.7 cm each) and its density (1.03 g/cm^3). From the values of the peaks (after the pedestals subtraction) and of the lost energy we define a polynomial as the one in Fig.8. Since we have subtracted the pedestals, our line will be ADC=m*E, where m, obtained by a fit, is equal to 80.

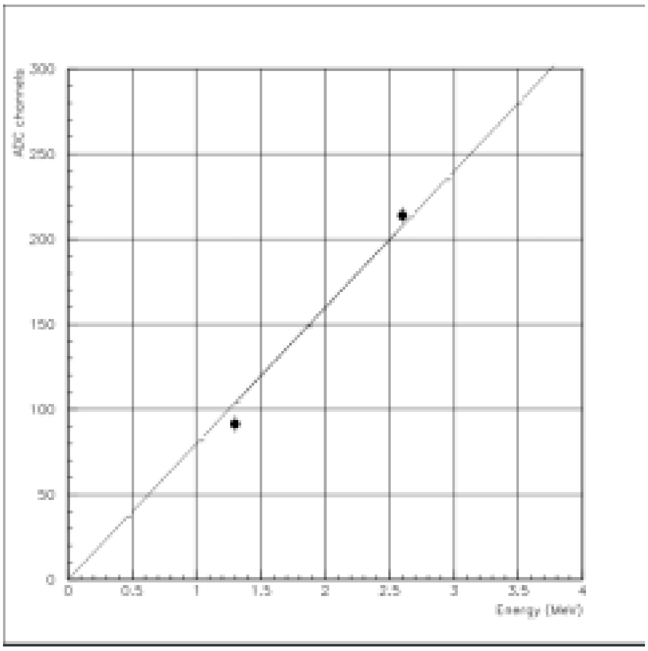


Fig. 8: *Calibration polynomial.*

HERMES

One example of a real experiment including the above detectors is Hermes in Hamburg [5]. Hermes (HERa MEasurement of Spin) is installed in the east-zone of Hera (High Energy Ring Anlage) in Desy (Deutsches Elektronen-Synchroton) research center. Hera is a double accumulation ring 6.3 Km long which uses positrons and protons beams, circulating in opposite directions. The Hermes detector is a spectrometer able to identify the different produced particles. This kind of apparatus uses only the Hera positron beam.

The beam is directed towards a target cell filled with Hydrogen, behind which there are scintillators and drift chambers. The particle track is bended by a dipole magnet and revealed by other drift chambers, a _erenkov detector (RICH) , a TRD, a preshower and an electromagnetic calorimeter made of 840 lead-glasses working as _erenkov counters.

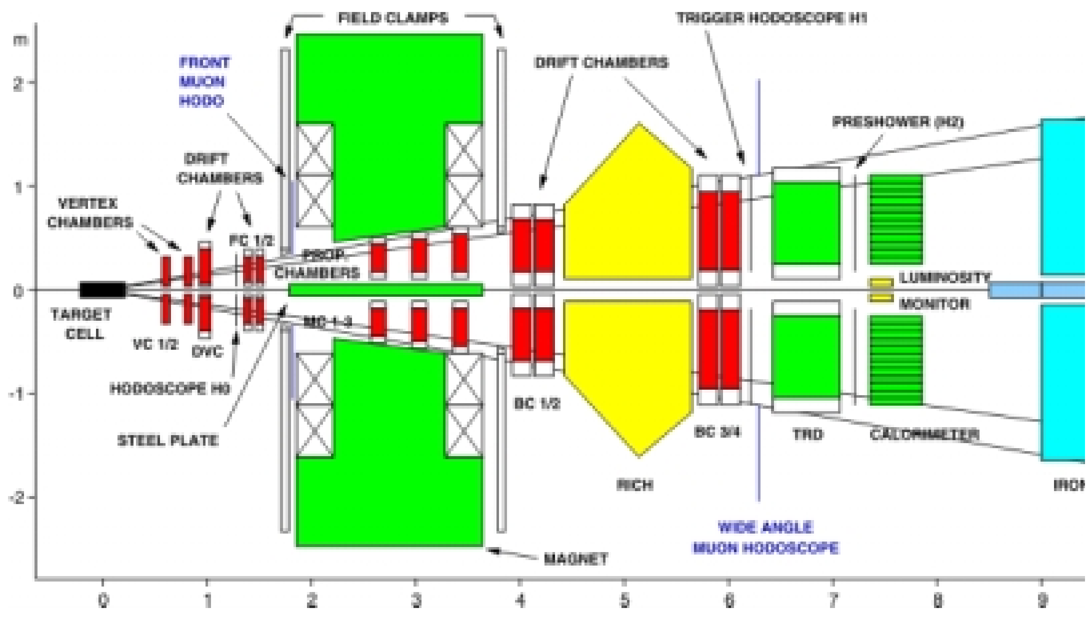
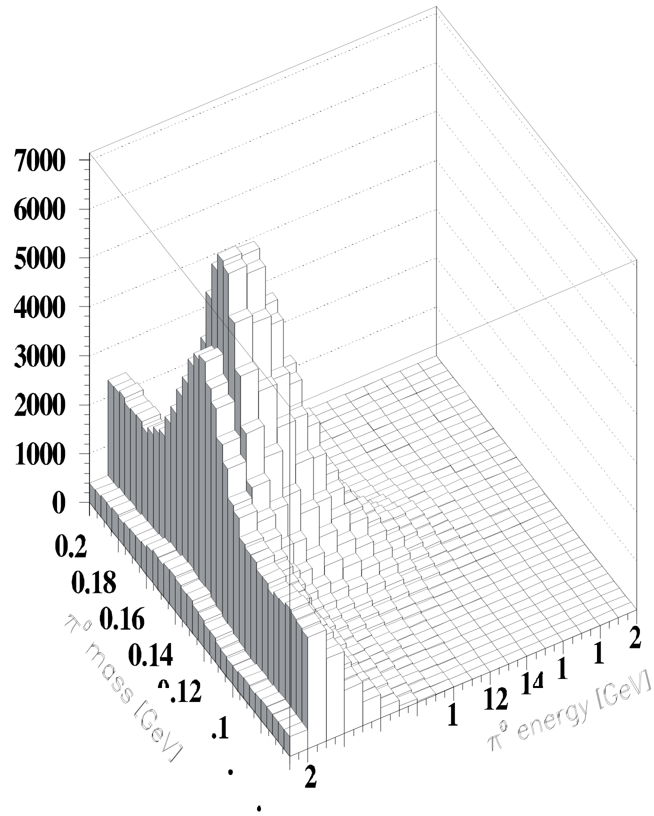


Fig. 8: *Hermes structure.*

ANALYSIS RESULTS

Some of the data from Hermes experiment have been analyzed through graphics referred to π^0 mass, root mean squared (rms) and the revealed background due to the uncorrelated detected photons. The identification of π^0 mesons is carried out through the invariant mass spectrum obtained from the revealed photons.



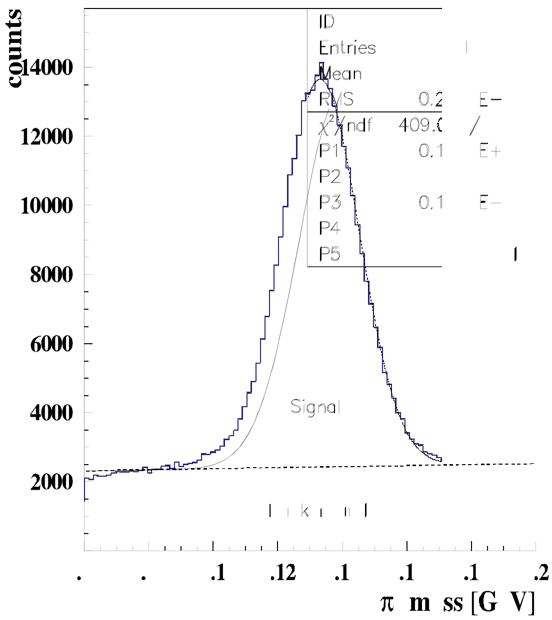


Fig. 9: *π^0 mass vs energy.*

Fig. 10: *π^0 invariant mass.*

This mass distribution is described by a gaussian for the peak, and a polynomial for the background. The content of the histogram above the polynomial between ±2_ around the average is considered as signal, that below the polynomial is considered as background. The three dimensional plot on the left shows the mass as a function of the energy. At low energy we have a considerable background, while at high energy it is almost negligible. On the right it is shown a mass spectrum with the fit parameters:

P1 is a normalization parameter, P2 is the mean value, P3 is the rms, P4 and P5 are the parameters of the background polynomial.

Each particle is identified by a quadrivector, defined by its momentum and energy:

$$|\vec{\vec{P}}| = (\vec{p}; iE) \qquad\qquad \vec{p} = m \cdot \vec{v}$$

It is important to mention that the norm of a quadrivector is the invariant mass of the relative particle:

$$|\vec{\vec{P}}|^2 = |\vec{\vec{P}}_1 + \vec{\vec{P}}_2|^2 = M^2_{\pi^0}$$

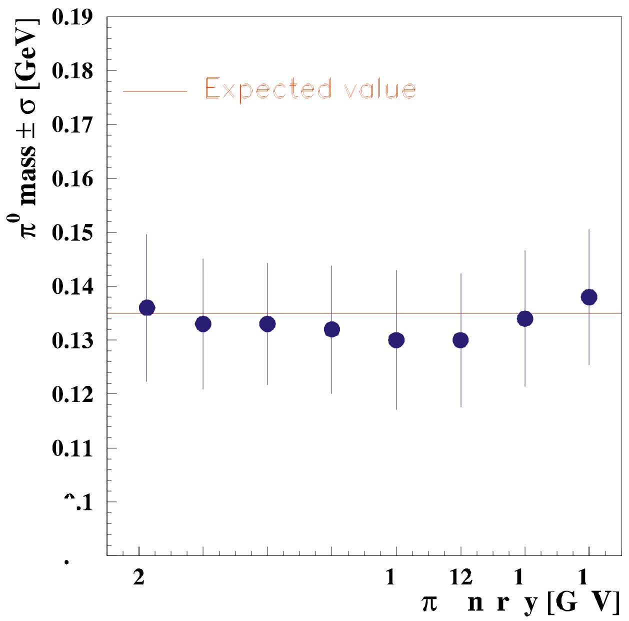


Fig. 11: *Mass spectrum.*

Considering the mass value in respect to 8 different bins in energy (2 GeV each), it has been observed that the variation of the mass doesn't change as a function of the energy and is well included in 1_, therefore close to the expected value of 0.135 GeV [6].

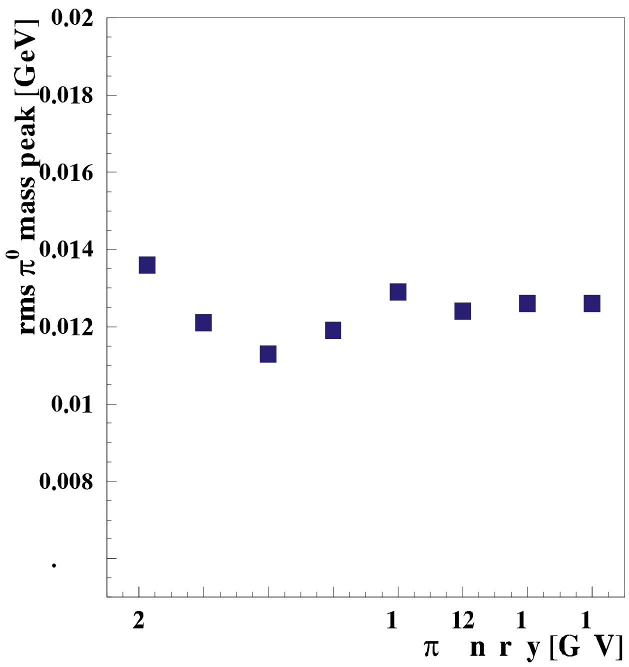


Fig. 12: *Rms variation.*

Similar to the mass, neither the _ variation is strongly connected to the π^0 energy increase. We define _ to be the rms, and in a gap of 2 _ we reveal the 95.4% of the events.

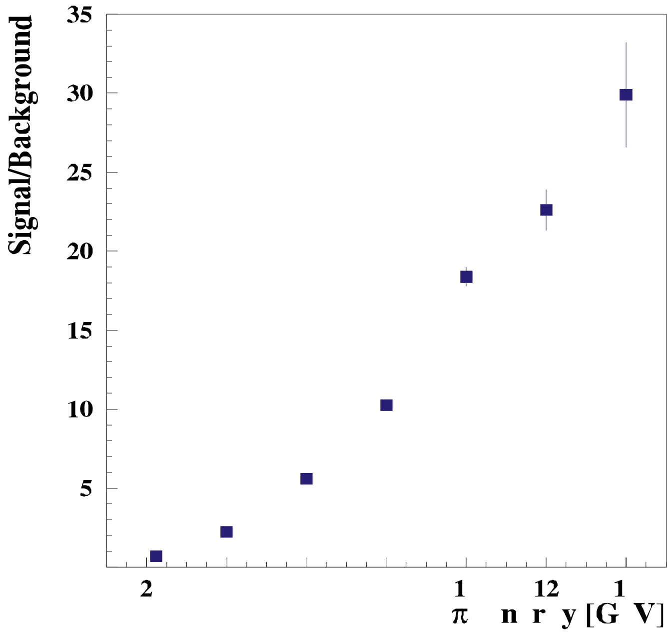


Fig. 13: *Signal over background ratio.*

In the above graphic is shown the signal over background ratio for the π^0 identification. We can see that, at the increase of the energy, the ratio increases as a function of the meson energy. This means that the uncorrelated photon pairs are present mainly at low energy. At high energy the π^0 signal strongly dominates even if also the number of events is reduced. The error bar represents the statistical error evaluated as:

$$Error = \frac{signal}{background} \cdot \sqrt{\frac{1}{signal} + \frac{1}{background}}$$

CONCLUSIONS

The data acquisition system we have built made us able to reveal clear cosmic ray signals, performing the tuning of the pedestals and the calculation of the calibration line. Moreover the data were compared between the detectors in single acquisition and in coincidence mode. Using data collected by the Hermes experiment, the kinematical properties of the π^0 mesons have been highlighted by the energy distribution studies and by the calculation of the relative ratio signal-over-background.

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