Che-Pmt

Development of a mobile detector of muon.

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Thank

Abstract

English Detection of astroparticles lean on instruments very varied according to the energy or the type of particles studed. The objective of the developpement of ChePMT (Čerenkov Portable Muon Telescope) is to have a detector of muon rustic, fickle, cheap, to stude such as the Forbush Decrease, the south Atlantic anomaly or to academic purposes, by detecting coincidence of Čerenkov signals between three stack little tanks of water.

Français La détection d'astropaticules s'appuit sur des instruments très variés selon l'énergie ou le type de particules que l'on souhaite étudier. L'objectif du développent de ChePMT (Čerenkov Portable Muon Telescope) est d'avoir un détecteur de muon à la fois rustique, versatile peu onèreu et leger pour étudier des phénomène comme les décroissances Forbush en physique solaire, l'étude de l'asymétrie de l'atlantique sud ou à des fins académiques, en détectant les coïncidences de trois petites cuves Čerenkov supperposées.

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Chapter 1

Historical introduction.

Genesis. In the early XX$^{\text{th}}$ century various experiences had shown the presence of an ionization of the air and the scientifics agreed to say that the radioactivity of the ground was responsible for. Nevertheless, different facts seemed to indicate that the radioactivity could not be the only phenomenon in cause.
-Firstly, mesurments on open sea indicated the ionisation of the air was still detectable in spite of the weak natural radioactivity of the water.
-Then there was the Theodor Wulf's experience in 1885, who had climbed on the Effel Tower'st top provided with an electroscope and discovred the dicrising of the rate of onization was height times less importante than if this ionization cames from the radioactivity of the earth.

Few years before the first world war, in 1909, Albert Göckel who reached FL 145, then in 1912 Vicor Hess, who reached FL 300 in balloons noticed that flux of particules grow with the altitude. This observations paved the way to the understunding of the phenomenon. However its real origin was still remaind to discovered. After the war, New records of altitude were established and with them, the ionizations of the atmosphere was completly characterized. it appeared that the ionization rised to 20 km then colapsed at higher height. this fact seemed to get its origin in the air. At last in 1925 Millikan mesured the charge flux in lacs at different altitudes and highlighted the spatial origin of this particules flux. Convinced that it was photons which provoked it, he named it **cosmic rays**.

Composition of the cosmic rays. the interwar years are a glorious period for the astroparticles. Firstly because the mesurment of the ionization rate in various points of the globe showed it depend of the latidude and the magnetic feild and indicated the cosmic rays are after all protons and nuclei. Secondly, the particle accelerator technology technology was for its stammerings there and the cosmics ray permited to produce many particuls which had never been observed and was discovered such as the positron in 1932, the muon in 1936 and just after the war, the pions π^+ and π^- in 1947.

Discovring of the extensive air showers. In 1938, Pierre Auger arrenged geiger conters in coincidence and detected corelated signals between them to the split milisecond. By taking away geiger counters, he demonstrated that space rays produced sheaves of secondary particles which extended over hundreds meters in diameters composed with Őlectrons, positrons and muons.

The revival of the study of astroparticles. After the second war, astroparticules undergoes a considerable disaffection. Nevertheless, a few nomber of experiences was risen with various type of detecors such as scintillators, UV camera, continued to be rised and especialy AGASA in Japan wich worked between 1990 and 2001. AGASA began to caracterise the spectrum of the flux of cosmic rays at very higth energy and paved the way to Pierre Auger, the great detector of expensive air shower. This detector, principaly based upon a network of 1600 Čerencov tank distributes on 3000 km^2 . Auger has to discover the origin of the most energetic astropaticles (E>10^{18} eV), there composition and will work at least until 2015.

Chapter 2

Theory.

2.1 The shape of the spectrum.

Generality. The flux of cosmic rays is manly component with a large part of protons and a few nombre of nuclei. from the ^{2}H to the ^{54}Fe. Its shape is very curious because it is caracterise by an isotropie and by one of the growth in law of power very regular (from 2,7 to 3) on more than ten orders of height it energie. This spectrum has been etablished by means of various methods according to the energies.

2.1.1 Heliospheric componant (E<$10^{9\text{-}10}$ eV).

The sweetest component of the flux of astroparticule has two origines. it mainly comes from particules of the galactic at this energies, there larmor radius is shorter than the size of the heliosphere and the particles are confined in the solar system either severly perturbat by it. In it is added an anisotrope component which is the one of the solar wind this low energetic component. At this energy, the paricles are influenced by the magnetiques field of the earth and by the geomagnetic cut off which varies from 15 GeV at the equator to 1 GeV at 60^{o} of latitud then even less near of the magnetic pole. This part spectrum has been characterised with satellite to avoid the influence of the geomagnetic field. Nevertheless, the solar wind which disrupt the galactic flux below 1 GeV impede for the moment to down lower then we are waiting the mesurement of voyager I and II which are to become the first artificial objects has to leave the solar system.

2.1.2 Galactic componant ($10^{9\text{-}10}$ eV<E<3 10^{18} eV).

The middles components of the the flux wich dicrise with a slope of power 2.7. They acquire there spectacular celerity in the supernova remnants according to a mechanism imagined by Enrico Fermi. When an energetique particles choc an area strongly magnetized, it bounce and gaind or loose enrergy according to it

choc frontaly the magnetic clowd or catch up it then as it is more probable to have a frontal choc, in average the particles accelerate.
This mecanism is efficient to rise a proton at an energy of the order of the EeV. Beyond 3 10^{15} eV the spectrum bent and the power decrease from -2.7 to -3.2 this bent is the **first knee**. It is followed by other knees which tally with the eavier elements from helium to iron. the cause of this bent is not very clear but it could come from a galactic deconfinment of the particles whose the Larmor radius overtake the galcactic size.

Detection. The detection in this scales of energy shall be etblisched with detector on-broard in atmospheric ballon under 10^{14} eV and by ground detectors for upper values.

2.1.3 Extragalactic componant (E>3 10^{18}eV).

The ankle. At more than the EeV the integral intensity of the flux harden and vary in $E^{-2.6}$ around 10 EeV . This **ankle** is a transition from the galactic component to an extragalactic component. At this energies the particles are little influenced by the galactic magnetic field and their trajectory in the galaxy is almost rectilinear allowing to reconstruct their trajectory and to find their origin, paving the way for protonic astronomy.

GZK cut Close to 100 EeV the particles are so energietic that the photons of the cosmologic microwave back ground is very blueshifted and can excite the protons in Δ^+ according to tree .

$$p + \gamma \rightarrow \Delta^+ \rightarrow p + \pi^0 \tag{2.1}$$

$$p + \gamma \rightarrow \Delta^+ \rightarrow n + \pi^+ \tag{2.2}$$

$$p + \gamma \rightarrow \Delta^+ \rightarrow p + \gamma \tag{2.3}$$

The protons undergo a progessive loss of energy and a variation of his way. So, the most energetic of them have to come from a limitad area around the galactica about 75 Mpc of radius. the Pierre Auger collaboration hoped to show a correlation of this cosmic rays origine and the Active galactic nuclei. Nevertheless, the results are not descisive because It seems that the flux grows heavy at ultra hight energy. That have to means the phisical mechanism which accelerat the extragalactic cosmic rays loss its efficiency and results of the intergalactic mangetic field (∼nG) has a significant effect on the trajectory of the nuclei and reduce considerabely the precision of the mesurment of the Pierre Auger Observatory.

2.2 Expensive air shower (EAS).

By penetring into the atmosphere, comsics rays interact with the atomes of the air and produce secondary particles which are the most of inization deteced by Göckel or Hess.

2.3 Hadronic showers.

At hight energy (E $\gtrsim 10^{14}$ eV) cascade of secondary particles are so energetic they can produce a shower of particles which can be detected upon tens, undreds or thousand metres for the most energetics.

Proton or nucleus interact by collising the atmosphere particles and prodiuce firstly an hadronic component whose the initial compostion varies with the energy of the primar. If the results of this reaction have been studed with particles accelerators to $\sim 10^{17}$ eV however the hadrons are mainly pions and kaons. The decrising of the hadrons interact with the atmosphere themself then decay to iniciat the leptonic cascades.
-muonic componant appear with the decay of charged pions and kaons.

$$\pi^+ \to \mu^+ + \nu_\mu \tag{2.4}$$

$$\pi^- \to \mu^- + \overline{\nu}_\mu \tag{2.5}$$

-electrons and photons are created by the decay of of the neutral hadrons

$$\pi^0 \to 2\gamma \tag{2.6}$$

$$N + \gamma \to e^- + e^+ \tag{2.7}$$

2.4 Electromagnetic showers.

Gamma ray burst (GRB). In 1973 the US army revealed the results of a program of russian nuclear trial surveillance. It seemed that for six years they detected cosmic sporadic sources of gamma photons. The gamma ray bursts can be divide in two classes. In a hand, there are the long gamma ray bursts whith a duration from a few seconds to a few minutes and an energie around 100keV and in an other hand, the short gamma ray bursts, which last 0.2 second in average and whose have an energy which can reachs the TeV.

The broad outline of a progenitor mecanisms,*collapstar*, of the long GRB is the collapse of heavy strars in fast rotation which could form two jets of ultra-relativiste mater. the origin of the short GRB is more mysterious but might find is origin in the collision of to stellar corps.

The showers. The second type of GRB has enough energy to produce showers of particles which can be detected at hight altitude. Nevertheless there composition is different of the hadronic shower because there is no hadronic component consequently, no muonic component. The showers are essentialy a cascade of reactions $\gamma \to e^- + e^+$ and $e^\pm \to \gamma + e^\pm$.

2.5 The choice of the muons.

Among the secondary particles emited by the cosmic rays approximatly 1% are muons and antimuons, or ten times less than electrons. But muons are 200 times heavier than the electons (105.66 MeV) then they do not almost interact with the matter. Also the decreasing of muons flux come essentialy from there spontaneous decay ($\mu^- \rightarrow e^- + \nu_\mu + \overline{\nu}_e$ or $\mu^+ \rightarrow e^+ + \nu_e + \overline{\nu}_\mu$). The mean lifetime of a muon is $2.196\mu s$ and the curve of emission seems to a gaussian centrered on $\sim$ 3 GeV the relativistic effects rise the lifetime to 60 μs and permit them to go through easely the atmosphere. Also, at sea level and under 2000 m of altitude the muons are the main component of the flux. Muons are not stopped easely by the matter but like evry charged particles it can produce Čerenkov light by passing in a transparent environment then it can be differentiat with an electron if the thickness of water is more than ten centimeters. All this caracteristic permit to the muon to be an exelent vector of information to stude cosmic rays and solar wind. The only particle which offer more pressision is the neutron but the price of the detectors are very expensive for 2001 and the Wall Street Center's attacks which have sky roketed the price of helium.

type of particle	Median energie of the detector
neutrons (n)	$\sim 20GeV$
muons (μ^+ & μ^-)	50-60 GeV
other (γ & e^-)	70-80 GeV

Table 2.1: Median energy of the primar particles deteced according to the type of detecor.

Chapter 3

Development of ChePMT.

3.1 Generality.

ChePMT is a detector of muons composed with tree tier of two cylindrical box. The upper box take in a Photo Multoplicator then the other is the tank of water.

3.2 Simulation.

LAGOSIM. The simulation of ChePMT were run using LAGOSIM, a variant of the program EASYSIM which had been developed to simulat the tanks of Pierre Auger Observatory. It is a simplify program which can simulate the answer of the an only tank for muons, electrons, or gammas, separately or in natural proportion. It is possible to fix the energie and the zenital origin of the particles. Nevertheless, the program do not simulat the mini-showers. It is possible to choose an constant energy and a vertical origine of the flux to reproduce the triggered spectrum of one tank.

Results of the simulation. The simulation indicat firstly that the particles emitted enought energy to be detected by the Photo-Multiplicator. Almost, it show the detector is efficient to discriminat the muonic component from the electrons and gammas.

Nevertheless the simulation indicate a weak point of the detector. The time of dicrising of the signal in the tank is to short for the data acquisition board. the effects of this fact on the mesurment are important. In a hand the charge which is estimat by integring of the signal take a low resolution then in the other hand the energy of the particles can be drastically under estimate.

3.3 Design.

3.3.1 The tanks.

The tree Čerenkov tanks are aluminum boxs of 6.4 cm of radius (R) and 15cm of height. The standrad aluminum of ChePMT's tanks have to major defects. Firstly, is reflect coefficient is close to 0.80. It seems quite good but to have a τ constant of the order of the aquisition time acquisition time (25 ns). In 25 ns the light is reflect 20 time edge of the box and after this rebonds, the signal down at 1% of the initial signal. Secondly, aluminum reflect the light like a mirror. Then we need to break the Černkov cone to have an homogenous signal. To make up for this problemes we paper the tank with a special tissu, Tyvek®, which has a reflect coefficient of 0.973 (it is this coefficient which was used to the simulation) and which can scatter the light.

3.3.2 Detector reponse and energetic spectrum.

Gain of the tank according to the zenithal angle. The gain of the detector is not constant with the arrival direction of the muons. The Čerenkov energy deposed in the tank evolves linearly with the cover distance inside, it change with azimuthal angle of the cosmic ray.

As regard the central detector, to have a coincidence with the other, the particule have to enters to the lid and goes out the floor. Thus, the deposed energy(E_d) is :

$$E_d(\theta) = 2MeV \frac{H}{cos(\theta)} \tag{3.1}$$

It mean the signal of the central detector is a quasi constant. the variation is 1.5% at $9.6^o(\theta_c)$ and 4.5% at $15.8^o(\theta_{max})$. For the upper and the lowest box, the particles can enters, respectively goes out by the broad. Then the signal falls down.

$$E_d(\theta) = 2MeV \begin{cases} \frac{H}{cos\ \theta} & \theta \in [0^o;\theta_c] \\ (\frac{R}{sin\ \theta} - \frac{1.5H}{cos\ \theta})^2 & \theta \in [\theta_c;\theta_{max}] \\ 0 & \theta > \theta_{max} \end{cases} \tag{3.2}$$

This no linearity of the gain of the extremal detecors could underestimate the number of low signal then deforms and translates the gaussian to the low signals for themself and to the hight signals for the central detector.

Angular origins of the particles. If the surface area of the tank is $A_0 = 129\ cm^2$ the effective area decrease with the zenithal origin.

$$A_\theta = \pi(R - \frac{3}{2}H\ tan\ \theta)^2 \tag{3.3}$$

To know the spectrum of the azimuthal origins we must take into account the variation of the flux of muon ($cos^3\theta$) and the solid angle ($sin\ \theta$) the angular density of probability is

$$\frac{dP}{d\theta}(\theta) = C\ A_\theta cos^3\theta\ sin\theta \tag{3.4}$$

With $C = 0.021\,m^{-2}$, a constant to normilise the integral to have $\int_0^{\theta_{max}} \frac{dP}{d\theta}(\theta)\,d\theta = 1$. By integring (3.4) between θ_c and θ_{max} we realize 17% of the particles are theoriticaly affected by the nolinearity. Fortunately the shut down of the gain affect the gausien of the signal when $\theta_{cg} = 12.7^o$ and the cut affect only 2.5% of the muons.

3.3.3 Other configuration.

A longer detector. We can set an empty box of 15cm between each tank of water to rise the angular resolution. the principe is the same but the values of the previous subsection are changed (θ_{med} is the median value of θ) .

config	$\theta_{med}(^{\rm o})$	θ_0	θ_{gc}	θ_{max}	f(Hz)	$\int_{\theta_c}^{\theta_{max}} \frac{dP}{d\theta}\,d\theta$	$\int_{\theta_{gc}}^{\theta_{max}} \frac{dP}{d\theta}\,d\theta$
normal	6.1	9.6	12.7	15.8	0.027	17%	2.5%
long	3.7	7.0	8.4	9.7	0.008	7%	1%

Table 3.1: angulars parameters of the two detectors

3.3.4 Electronique.

3.4 The preliminar datas.

Chapter 4

Application.

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4.1.2 The excess of muons the gamma-ray burst.

4.2 Forbush decrease.

4.3 Other applications.

4.3.1 Calibration.

4.3.2 trigger

4.3.3 Academic use.

Chapter 5

Conclusion.

Appendix A

Annexe