The GBAR Experiment and Cosmic Ray Analysis

2011-11526 Nojune Park

Abstract

The GBAR experiment aims to measure antimatter's acceleration in gravitational field. For this, we would make anti-hydrogen atom free-fall in earth's gravity field. Scintillator and PMT would be used to calculate acceleration. During an internship program, I made detector by using scintillator and PMT, and tested its usability. In the meantime, since scintillator could detect cosmic ray, we also consider it as background. Background analysis is also involved in this report. Height distribution follows landau function and angular distribution agree with the expectation.

1. Introduction of the GBAR Experiment

1.1 scientific motivation

It has long been known by scientists that in nature, there are fundamental forces, gravity and electromagnetic force. They are both inversely proportional to square of distance and directly proportional to each matter's 'charge'. But they have difference in action direction, specifically, gravity exerts always attractively while electromagnetic force works attractively or repulsively. This is still true in all experiments carried out past and present, although new forces and particles are discovered. This difference originated from their 'charges', electromagnetic force has two opposite charges which interact attractively in opposite pair and repulsively in same pair, while gravity has only one charge which interact always attractively. But after antimatter had been discovered which has opposite electric charge to matter, the possibilities are brought up that antimatter could have opposite gravity charge to matter. According to WEP, inertial mass of antimatter is equal to matter, so if antimatter have opposite gravity charge, it acts repulsively in gravity field. In this situation, antimatter's acceleration is GBAR.

Made by synthesizing many modern physics theories and experiments, standard model had explained diverse natural phenomenons, but still there are a lot of questions it could not explain. Why antimatter are observed less than matter in the Universe? Why CPT symmetry is violated in nature? For giving explanation, some theories modified from standard model was brought up, some of which contain components inducing repulsive gravity (ref[1]). Furthermore, the fact that dark energy behaves like repulsive gravity arouse physicist's interest in anti-gravity. In this sense, the GBAR experiment is interesting subject in particle physics.

1.2 experimental scheme (Ref[1])

To measure GBAR, one needs some slow antimatter. Considering electromagnetic influence and manipulability, we would use antihydrogen atom. Meanwhile, to enough slow down the speed, first we prepare $\overline{H}^{+}$ atom. This experiment conducted in accordance with following procedure.

-From the interactions of a thin tungsten target and electron beam by a small accerelator, fast positrons produced.

- positrons are moderated to slow down and accumulated inside a high field Penning-Malmberg trap, where they ejected onto a mesoporous silica target to form a o-Ps cloud.
- anti-protons from ELENA and AD are interacting with o-Ps, produce $\overline{H}$ and $\overline{H}^{+}$

$$\overline{p}+Ps\rightarrow\overline{H}+e^{-}$$
$$\overline{H}+Ps\rightarrow\overline{H}^{+}+e^{-}$$

- anti-hydrogens are cooling in a Paul trap and detached excess positron by laser.
- detecting is conducted to measure free-fall of an anti-hydrogen atom

2. Detectors

2.1 Scintillator (Ref[2])

scintillation detector is used widely in nuclear and particle physics. It makes light signal when nuclear particle or radiation is incident to it. So by using it, physicist can know the existence of particles and their trajectory and incident timing. In GBAR experiments, it is used for speculating anti-hydrogen's decay position. When using it, one also must consider the interaction with incident cosmic radiation.

2.2 PMT (Ref[2])

Photo multiplier tube is a detector which transform incident photon to electric current by photo electric effect. Attached to scintillator, it could make scintillation convert to electrical pulses, so that one can analyze the information of the incident radiation or particle. One should be careful about the noise made by dark current or after-pulsing, or statistical noise produced by statistical nature of photo electric effect and multiplier system.

2.3 Muon detecting

When muon pass through matter, it interact with matter, which cause to lose its energy. The interaction contains muon scattering from atomic electrons, bremsstrahlung on atomic electrons, electron pair production and photonuclear interaction with a general nucleon. (Ref[3])
The Bethe-Bloch Formula could be used energy loss calculation. (Ref[2])

$$-\frac{dE}{dx} = 2\pi N_a r_e^2 m_e c^2 \rho \frac{Z}{A}\frac{z^2}{\beta^2}\left[\ln\left(\frac{2m_e\gamma^2 v^2 W_{\max}}{I^2}\right) - 2\beta^2\right]$$

$$W_{\max} = \frac{2m_e c^2\eta^2}{1+2s\sqrt{1+\eta^2}+s^2}$$

In addition, energy loss distribution is calculated by Landau theories. (Ref[2])

$$f(x,\delta) = \phi(\lambda)/\xi,\ where$$

$$\phi(\lambda) = \frac{1}{\pi}\int_0^\infty \exp[-u\ln u - u\lambda]\sin\pi u\,du$$

$$\lambda = \frac{1}{\xi}[\delta - \xi(\ln\xi - \ln\epsilon + 1 - C)]$$

In our lab, absorbing material is the EJ-200 scintillator, and muon's speed is about 0.92c. (Ref[5]) then result is

$$\frac{dE}{dx} = 1.685\,[MeV/cm]$$

Considering light output of EJ-200, the number of photons produced by muon is about 9.13x10^4. Calculating probability of total reflection with critical angle 39.3, area ratio of PMT/Scitillator cross sectional area 39.2% and quantum efficiency about 10%, the number of photoelectrons produced in PMT is 7.79×10^2.

Considering PMT gain 1.1×10^6, from $Q == Vt-R$,

$$Vt = RQ = 6.68\times10^{-9}[Vs] = 1.10\times10^4[Adc\times ns].$$

One could compare this result with actual Data analysis. The following histogram is signal integral of incident muon.

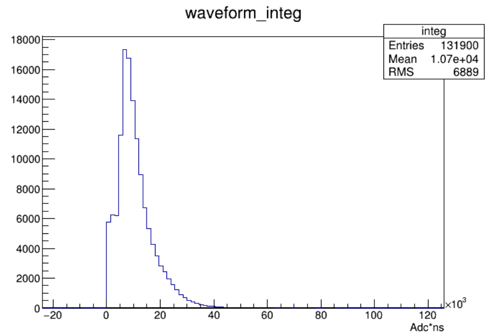


figure 1. signal integral to time

Comparing mean value of data, the error is 2.8%, which shows this calculation was meaningful.

3. The Cosmic Ray (Background) (Ref[4])

The cosmic ray is incident radiation or particles from out of the terrestrial atmosphere. It is divided into two types, one is primary which includes particles flying from astrophysical sources, the other is secondaries which includes particles produced by interaction of the primary with interstellar gas. Its main constituent material is proton(H+), about 10% of helium and small amount of Li, Be, B, etc. Its energy and ratio depend on solar activity such as solar wind, flares, or expanding magnetized plasma generated by the Sun.

4. Data Analysis

All experiments are done with 2bar (2 scintillators and 4 PMTs attached left and right side of each scintillators). Coincidence time is set to 200ns.

4.1 height distribution

For each signal read in detector, one could find maximum value called height. The following pictures are height distribution measured at each PMT. The lines are landau function fitted in each distribution. One could see all histograms are well fitted.

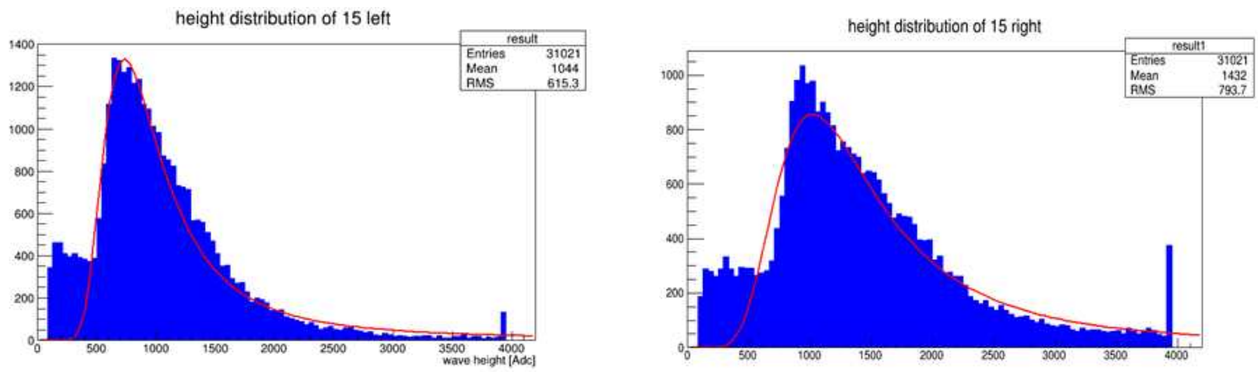


figure 2 height distribution of muon

4.2 angular distribution

From the difference between left and right trigger time, one could estimate where muon pass through on scintillator. Each traces are represented in 2d histograms.

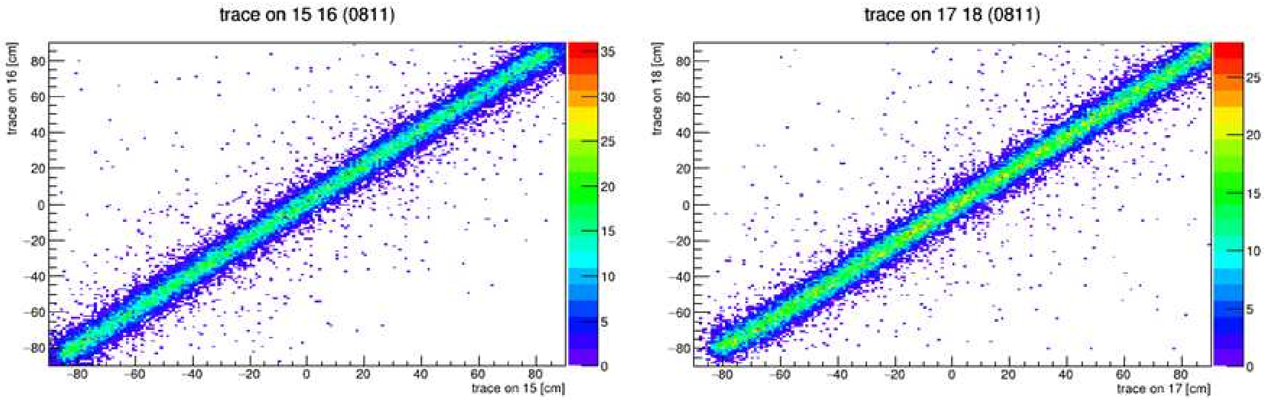


figure 3 trace of muon on each scintillator

Using this result, one could draw angular distribution of cosmic ray. The following histograms are cosine of angular dist.

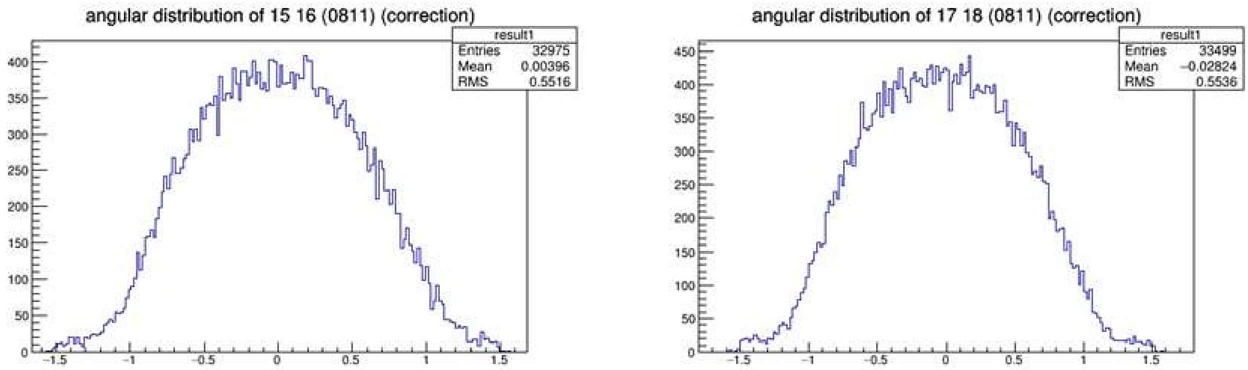


figure 4 angular distribution of muon

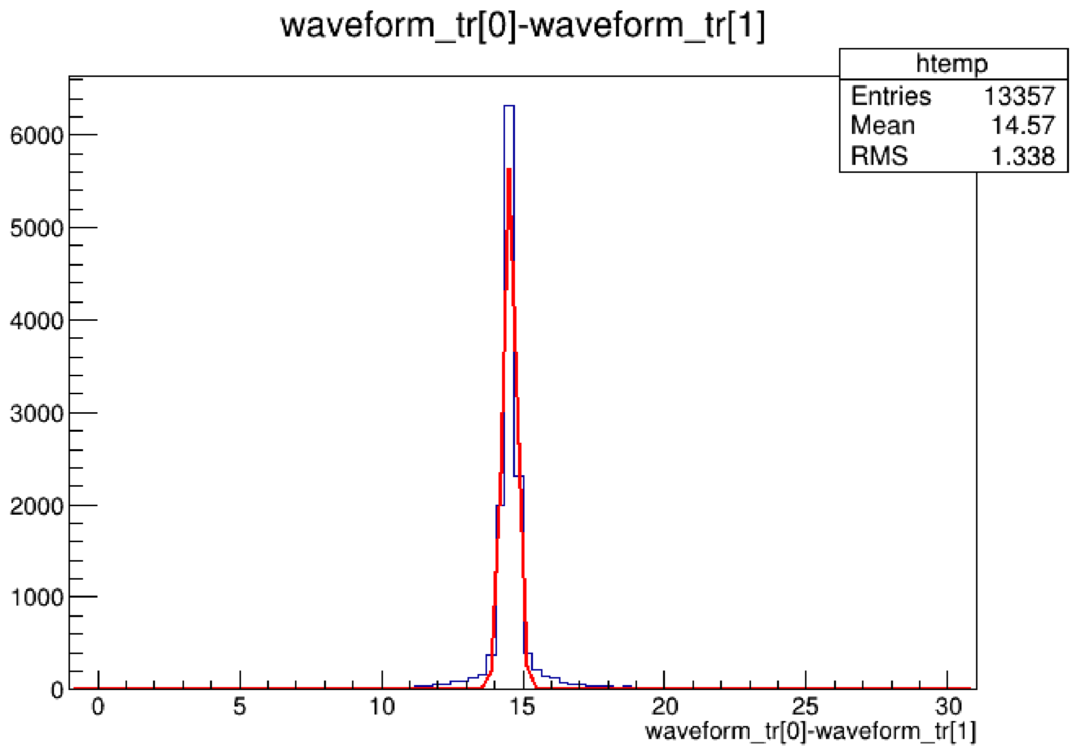
5. summary

During the internship program, I could learn about techniques related with particle physics. Studying detectors and ROOT, I could prepare basic knowledge about particle physics. Also from actual data analysis, I could achieve understanding about cosmic ray and their distributions. Furthermore, I was able to know what GBAR is and how physicists measure it. This experience would be very helpful to study after my graduation.

Reference

[1] The GBAR experiment:gravitational behaviour of antihydrogen at rest, P Perez and Y Sacquin, 2012
[2] Techniques for Nuclear and Particle Physics Experiments, William R. Leo.
[3] http://antares.in2p3.fr/users/bailey/thesis/html/node73.html
[4] Particle Physics Booklet, 2016
[5] Measurement of the Speed and Energy Distribution of Cosmic Ray Muons, Grant Remmen and Elwood McCreary, 2012

time resolution test



sigma : 251 ps