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Development of YAC (Yangbajing Air shower core array) to be used for next phase of Tibet experiment

Y.Katayose[a], M.Shibata[a], K.Kimura[a], L.K.Ding[b], N.Hotta[c], H.B.Hu[b], J.Huang[d], K.Kawata[d], M.Ohnishi[d], H.Onuma[e], T.Ouchi[f], T.Y.Saito[d], T.Saito[g], A.Shiomi[d], H.Sugimoto[h], M.Takita[d], Y.H. Tan[b], H.Tsuchiya[i], and T.Yuda[f]

(a) Department of Physics, Yokohama National University, Yokohama 240-8501, Japan
(b) Institute of High Energy Physics, Chinese Academy of Sciences , Beijing 100049, China
(c)Faculty of Education, Utsunomiya University, Utsunomiya 321-8505, Japan
(d)Institute for Cosmic Ray Research, University of Tokyo, Kashiwa 277-8502, Japan
(e)Department of Physics, Saitama University, Saitama 338-8570, Japan
(f)Faculty of Engineering, Kanagawa University, Yokohama 221-8686, Japan
(g)Tokyo Metropolitan College of Aeronautical Engineering, Tokyo 116-0003, Japan
(h)Shonan Institute of Technology,Fujisawa 251-8511, Japan
(i)RIKEN, Wako 351-0198, Japan
Presenter: Y.Katayose(katayoes@ynu.ac.jp)jap-katayose-Y-abs1-he15-poster

We have been developing a new type of air shower core array (Yangbajing Air shower Core array:YAC) to observe the cosmic-ray composition at the knee energy region. YAC array is going to be operated with TibetIII air shower array at Yangbajing(China). TibetIII is used to observe the total energy and the direction of an air shower and YAC observes high energy secondaries around the air shower core. Each YAC detector consists of lead plates of 3.5cm thick and a scintillation counter. The burst size of air shower core can be measured with the dynamic range from 1 MIP to 10^6MIPs(Minimum Ionization Particle). Small test array with 4 YAC detectors have been constructed near the center of TibetIII array. Each detector has been operated with the threshold of the burst size 40 particles. Trigger rate of each detector is 0.15 Hz approximately. The performance of the test array has also studied by Monte Carlo simulation with "Cosmos DPMJET3" code. The observed spectrum of the burst size is consistent with the Monte Carlo simulation.

1. Introduction

The observation of the energy spectrum between 10^{14} eV and 10^{16} eV called "knee region" is essentially important to solve the acceralation mechanism of the cosmic rays. The investigation of the chemical composition has been made with various instruments on board satellites or balloons, however, the observed energy range is limited up to a few hundred TeV because of their extremely low fluxes, where protons are the main component and the change of spectral index has not been confirmed yet. For the energies over PeV, several observeations have been made by many air shower experiments, however, the chemical composition remains still unclear. We have measured both all-particle spectrum and proton spectrum in the energy range $10^{14} \sim 10^{16}$ by the hybrid instruments consisting of the air shower core detector (emulsion chamber and burst detector) and TibetIII air shower array [1], [2]. Our results suggest that the main component at the knee is heavy particles (heavier than helium) because of the low intensities of observed proton and helium fluxes, whose sumed flux are less than 30 % of all particles [3]. We have a plan to observe the heavier component (Iron and CNO∼VH) explicitly by a new air shower core detector (YAC). In this paper, the design of YAC, the performance of the detector and the results of test experiment are described.

2. Air shower core detector

To observe heavy component at the knee energy region, a design study of a new detector has been made by Monte Carlo simulation [4]. A new detector consists of lead plates, which convert the high energy secondaries

into electrons, and a scintillation counter. For the observation of the iron spectrum, we found that the optimized thickness of lead is 3.5cm and distance between each detector center is $3 \sim 4$ m approximately with trigger condition of burst size greater than 100 as shown in Fig. 1. YAC array is going to be operated with TibetIII air shower array at Yangbajing (China). TibetIII is used to observe the total energy and the direction of an air shower and YAC observes high energy secondaries around the air shower core. The energy range of iron spectrum observed by YAC array is from a few 10^{15}eV to 10^{17}eV. Therefore the burst size of each YAC is from a few hundred MIPs to 10^6MIPs. On the other hand, the signal of one MIP will be calibrated by single cosmic muons. In other words, it is required that YAC should have the wide dynamic range from 1 MIP to 10^6 MIPs.

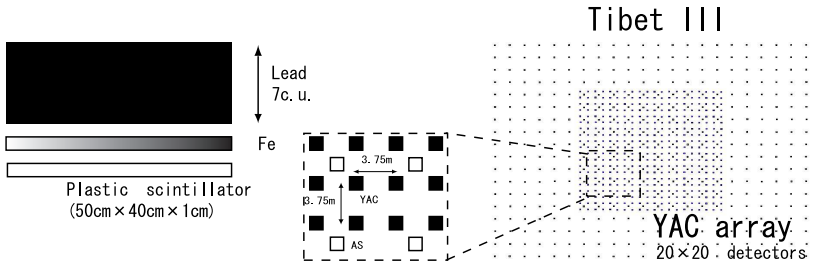

Figure 1. Design of YAC detector.

[Dynamic range]
The signal of scintillator is read out with wave length shifting fibers (WLSF, KURARAY, Y11 $\phi = 1.5$mm) and two types of PMTs (HAMAMATSU R4125 and R5325), which have different gains each other, as shown in Fig. 2. Fig. 3 shows the measured dynamic range of both PMTs. Higher gain PMT R4125 is used to measure light yield from 1 MIP to a few thousand MIPs, where the gain is adjusted to about 2.5pC for 1MIP, while lower gain PMT R5325 is used in the dynamic range from a few hundred to 10^6 MIPs.
[Uniformity]

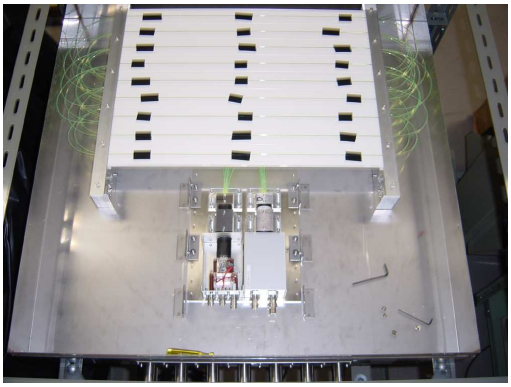

Figure 2. Components of YAC detector.

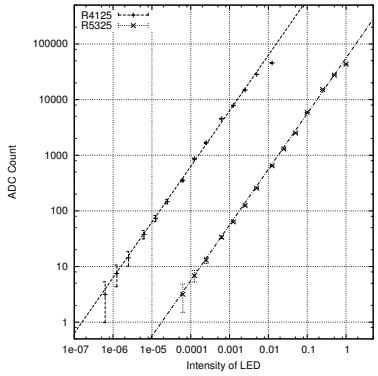

Figure 3. The dynamic range of R4125 and R5325. Blue LED pulse is measured by both PMTs. LED is driven by TTL level pulse with the width of 25nsec. The resolution of ADC count is 0.25pC/count.

One unit of YAC's scintillation counter consists of a scintillator with the size of 50cm $\times$ 40cm $\times$ 1cm and 10

WLSFs which are installed inside the scintillator with the gap of 5cm. The both edges of WLSF are attached to a PMT to read out scintillation light yield as shown in Fig.2. The position dependence of light yield has been measured by cosmic muons with the experimental setup as shown in Fig. 4. Fig. 5 shows the uniformity of light yield. The uniformity in the length of 50cm is better than $\pm 5\%$.

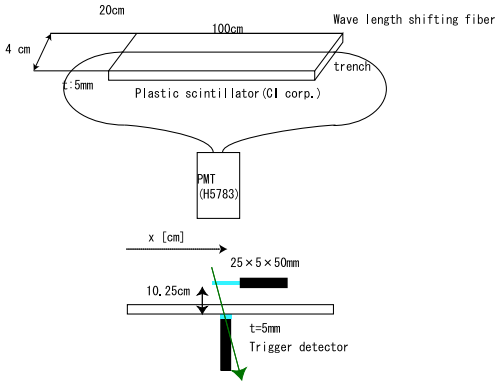

Figure 4. An experimental setup for muon measurement.

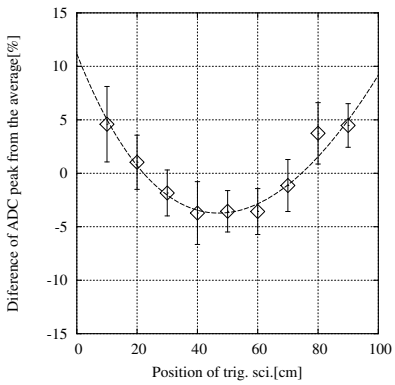

Figure 5. The position dependence of light yield for the scintillator with WLSF used in YAC.

3. Test experiment

Small test array with 4 YAC detectors have been constructed near the center of TibetIII. Each detector has been operated with the threshold burst size of 40 particles. Trigger rate of each detector is 0.15Hz approximately.

[Calibration]

The pulse charge of the higher gain PMT(R4125) has been calibrated with cosmic muons. Muons have been triggered by small plastic scintillator put on YAC. Fig. 6 shows the charge distribution of R4125 by cosmic muon. The peak is about 0.7pC and σ is 0.4pC approximately. For lower gain PMT, the pulse charge is converted to the particle number using both the single muon peak of the high gain PMT and the ratio of the gain between higher and lower gain PMTs. To measure this correlation, the same air shower core events have been observed by both types of PMTs. The relation of two PMTs is linear in the region from a few hundred pC to thousand pC for R4125 as shown in Fig 7.

[Analysis]

Data from about 100 days have been analyzed and compared with Monte Carlo simulation. Fig. 8 shows the observed spectrum of the burst size (Nb) by a YAC detector. The events have been selected under the condition that the threshold of Nb in each YAC is 100 particles and number of hit detector is 4. Black points show experimental data and dots show Monte Carlo simulation. “Cosmos” simulation code is used with the interaction model of “DPMJET3”. Experimental flux is consistent with Monte Carlo simulation.

4. Conclusions

A new type air shower core detector (YAC) has been developed to observe the cosmic-ray composition at the knee energy region. Each YAC detector consists of lead plates of 3.5 cm thick and a scintillation counter. The dynamic range of a YAC is from 1 MIP to 10^6 MIPs. Small test array with 4 YAC detectors have been constructed in TibetIII. The results observed by test array are consistent with Monte Carlo simulation. It is confirmed that a new detector has sufficiently high performance to measure air shower core with the burst size from a few hundred to 10^6.

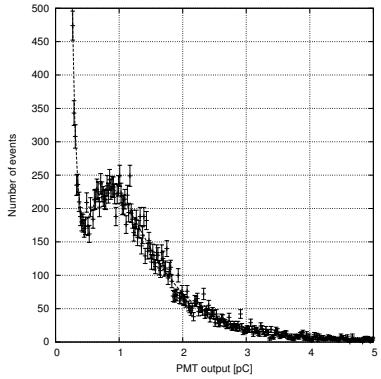

Figure 6. Charge distribution of a high gain PMT with single cosmic muons. Peak is 0.7pC and σ is 0.4pC approximately.

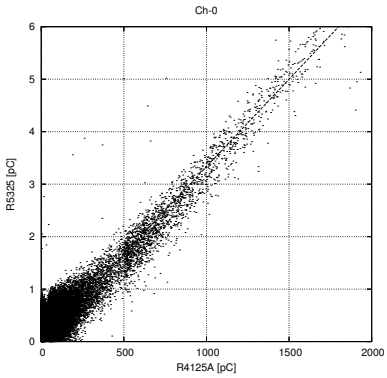

Figure 7. Correlation between higher gain PMT and lower one.

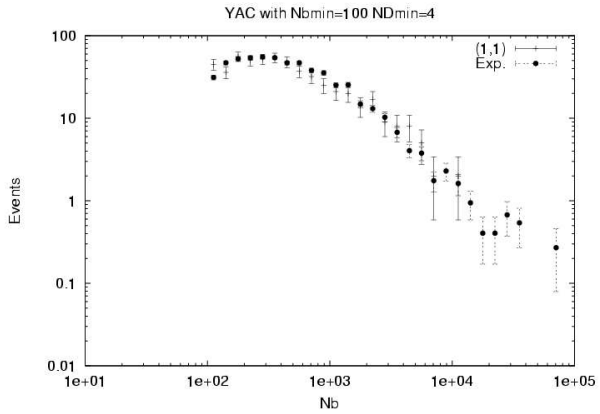

Figure 8. Burst size spectrum.

5. Acknowledgments

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