Calibration of the Yangbajing air-shower core detector (YAC) using the beam of BEPC

M. AMENOMORI[1], X. J. BI[2], D. CHEN[3], W. Y. CHEN[2], S. W. CUI[4], DANZENGLUOBU[5], L. K. DING[2], X. H. DING[5], C. F. FENG[6], ZHAOYANG FENG[2], Z. Y. FENG[7], Q. B. GOU[2], H. W. GUO[5], Y. Q. GUO[2], H. H. HE[2], Z. T. HE[4,2], K. HIBINO[8], N. HOTTA[9], HAIBING HU[5], H. B. HU[2], J. HUANG[2], W. J. LI[2,7], H. Y. JIA[7], L. JIANG[2], F. KAJINO[10], K. KASAHARA[11], Y. KATAYOSE[12], C. KATO[13], K. KAWATA[3], LABACIREN[5], G. M. LE[2], A. F. LI[14,6,2], C. LIU[2], J. S. LIU[2], H. LU[2], X. R. MENG[5], K. MIZUTANI[11,15], K. MUNAKATA[13], H. NANJO[1], M. NISHIZAWA[16], M. OHNISHI[3], I. OHTA[17], S. OZAWA[11], X. L. QIAN[6,2], X. B. QU[2], T. SAITO[18], T. Y. SAITO[19], M. SAKATA[10], T. K. SAKO[12], J. SHAO[2,6], M. SHIBATA[12], A. SHIOMI[20], T. SHIRAI[8], H. SUGIMOTO[21], M. TAKITA[3], Y. H. TAN[2], N. TATEYAMA[8], S. TORII[11], H. TSUCHIYA[22], S. UDO[8], H. WANG[2], H. R. WU[2], L. XUE[6], Y. YAMAMOTO[10], Z. YANG[2], S. YASUE[23], A. F. YUAN[5], T. YUDA[3], L. M. ZHAI[2], H. M. ZHANG[2], J. L. ZHANG[2], X. Y. ZHANG[6], Y. ZHANG[2], YI ZHANG[2], YING ZHANG[2], ZHAXISANGZHU[5], X. X. ZHOU[7] (THE TIBET ASγ COLLABORATION)

[1]*Department of Physics, Hirosaki University, Hirosaki 036-8561, Japan*
[2]*Key Laboratory of Particle Astrophysics, Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China*
[3]*Institute for Cosmic Ray Research, University of Tokyo, Kashiwa 277-8582, Japan*
[4]*Department of Physics, Hebei Normal University, Shijiazhuang 050016, China*
[5]*Department of Mathematics and Physics, Tibet University, Lhasa 850000, China*
[6]*Department of Physics, Shandong University, Jinan 250100, China*
[7]*Institute of Modern Physics, SouthWest Jiaotong University, Chengdu 610031, China*
[8]*Faculty of Engineering, Kanagawa University, Yokohama 221-8686, Japan*
[9]*Faculty of Education, Utsunomiya University, Utsunomiya 321-8505, Japan*
[10]*Department of Physics, Konan University, Kobe 658-8501, Japan*
[11]*Research Institute for Science and Engineering, Waseda University, Tokyo 169-8555, Japan*
[12]*Faculty of Engineering, Yokohama National University, Yokohama 240-8501, Japan*
[13]*Department of Physics, Shinshu University, Matsumoto 390-8621, Japan*
[14]*School of Information Science and Engineering, Shandong Agriculture University, Taian 271018, China*
[15]*Saitama University, Saitama 338-8570, Japan*
[16]*National Institute of Informatics, Tokyo 101-8430, Japan*
[17]*Sakushin Gakuin University, Utsunomiya 321-3295, Japan*
[18]*Tokyo Metropolitan College of Industrial Technology, Tokyo 116-8523, Japan*
[19]*Max-Planck-Institut für Physik, München D-80805, Deutschland*
[20]*College of Industrial Technology, Nihon University, Narashino 275-8576, Japan*
[21]*Shonan Institute of Technology, Fujisawa 251-8511, Japan*
[22]*RIKEN, Wako 351-0198, Japan*
[23]*School of General Education, Shinshu University, Matsumoto 390-8621, Japan*

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Abstract: Aiming at the observation of cosmic-ray chemical composition at the knee energy region, a new type air-shower-core detector (YAC, Yangbajing Air shower Core array) has been developed and set up at Yangbajing, 4300 m a.s.l. in Tibet, China since August, 1st, 2011. YAC will work together with the Tibet-III array and a large muon detector as a hybrid experiment. Each YAC detector unit consists of lead plates of 3.5 cm thick and a scintillation counter which detects the burst size induced by high energy electromagnetic component in the air-shower cores. The burst size is demanded to be measured from 1 MIP (Minimum Ionization Particles) to 10^6 MIPs. The linearity and the saturation of the plastic scintillator and PMT used in the YAC detector have been studied with the accelerator beam of the BEPCII (Beijing Electron Positron Collider, IHEP, China). The accelerator-beam experiment shows a good linearity between the incident particle flux and YAC-ADC output below 5×10^6 MIPs and the saturation effect of the plastic scintillator satisfies YAC detector's requirement.

Keywords: cosmic ray, knee, air shower

1 Introduction

The all-particle energy spectrum of primary cosmic rays is well discriminated by a power law dN/dE $\propto$ E$^{-\gamma}$ over many orders of magnitude, with γ changes sharply from 2.7 to 3.1 at about 4 PeV [1]. For explaining the sharp knee we proposed two composition models (called Model A and Model B)[2]. In model A, an excess component is assumed to overlap the global component, and its spectrum shape suggests that it can be attributed to nearby source(s) because it is surprisingly close to the expected source spectrum of the diffuse shock acceleration. Middle composition is predicted by this model at the knee. However, in model B, a hard observed energy spectrum of each element from a given source is assumed. The sharp knee can be explained by a rigidity-dependent acceleration limit and hard spectrum due to nonlinear effects. Iron-dominant composition is predicted by model B at the knee and beyond.

In order to distinguish between Model A and Model B and many other models, measurements of the chemical composition around the knee, especially measurements of the spectra of individual component till their knee will be essentially important. Therefore, we planed a new experiment: 1) to lower down the energy measurement of individual component spectra to *10TeV and make connection with direct measurements; 2) to make a high precision measurement of primary P, He, C, Iron till 100 PeV region to see the rigidity cutoff effect. Therefore, we designed a new AS core detector array – YAC (Yangbajing AS Core array), to detect the high energy electromagnetic component of the air-shower cores at Yangbajing, Tibet, mainly for the measurement of spectra of individual component (P, He, Iron and other nuclei) till their knee region.

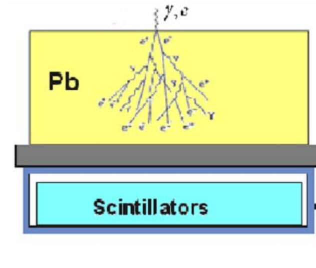

Figure 1: Each YAC detector unit consists of lead plates of 3.5 cm thick and a scintillation counter which detects the burst size induced by high energy electromagnetic component in the air-shower cores.

Figure 2: Each YAC's scintillation counter consists of 20 slabs of scintillator whose size is 50 cm $\times$ 4 cm $\times$ 1 cm, and light-isolated from each other using reflecting material. 20 WLSFs installed in the scintillators attached to the PMT R5325, the other 40 WLSFs attached to PMT R4125, that are responsible for the dynamic range of 1-5000 and 10^3 - 10^6, respectively.

2 Yangbajing air-shower core detector

Each YAC unit consists of lead plates of 3.5 cm (7 r.l.) thick and a scintillation counter which detects the burst size induced by high energy electromagnetic component at the air-shower core (Fig. 1). The burst size threshold is set to $\sim$100 particles which corresponds to $\sim$ 30 GeV of electromagnetic component incident upon a detector. Each YAC's scintillation counter (see Fig. 2) consists of 20 scintillator slabs whose size is 50 cm $\times$ 4 cm $\times$ 1 cm, and light-isolated from each other using reflecting material. While 20 WLSFs (wave length shifting fibers; SAINT-GOBAIN BCF-92, round cross section with 1.5 mm diameter)installed in the scintillator slabs attached to the PMT R5325, the other 40 WLSFs attached to PMT R4125. One end of the WLSF is attached to a PMT for readout, another end is alumimium-filled for reflecting photons, and the reflection rate reaches 99%.

The signals produced in the plastic scintillator are transmitted to two different gain photomultiplier tubers (PMTs), respectively, via WLSF; in order to record the electromagnetic showers of energies from *GeV to 10 TeV, a wide dynamic range from 10^1 to 10^6 MIPs (Minimum Ionization Particles) of PMT is requested. In addition, taking into account the importance of single particle measurement in the system calibration, the dynamic range of PMT should be from 1 to 10^6 MIPs. This is realized by adopting a high gain PMT (HAMAMATSU R4125) and a low gain PMT (HAMAMATSU R5325) that are responsible for the range of 1- 5$\times 10^3$ MIPs and 10^3 to 10^6 MIPs, respectively. Therefore, there is some overlap range between two different gain PMTs. The linearity of the YAC detector in the full dynamic range (from 1 to 10^6 MIPs) will be studied later.

The main purpose of the measurement described in this paper was to check whether: (1) Two selected different gain PMTs are adaptable for a large dynamic range, from 1 to 10^6 MIPs. (2) The plastic scintillator used in YAC detector is not saturated with a beam intensity upto 10^6 electrons / (cm^{2}s).

3 YAC detector calibration

1. PMT R4125 and R5325 calibration by LED light source:

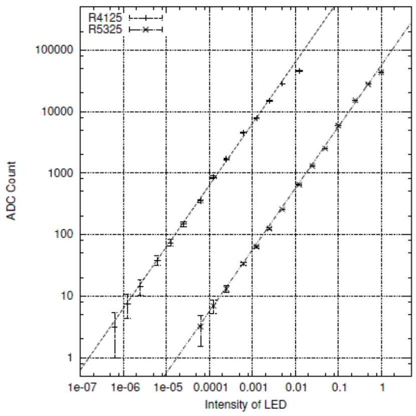

Figure 3: PMT R4125 and R5325 calibration by LED light source.

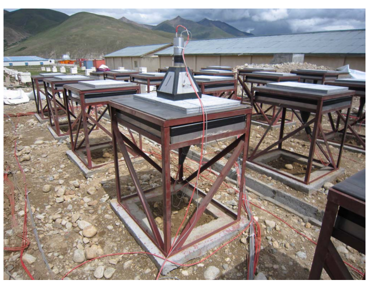

Figure 4: The Probe calibration.

For every PMT (high gain (R4125) and low gain (R5325)) used in YAC-II, the linearity is measured using LED light source and optical filters [3]. In the test, we fixed the positions of LED, filter and PMT. By using different filters we get light of different intensity as shown in Fig. 3. The LED is driven by TTL pulse with the width of 25 nsec. The resolution of ADC count is 0.25 pC/count. From Fig. 3, we found that, taking the scintillation light intensity and the knowledge from the probe calibration (see below) into account, high gain PMT (HAMAMATSU R4125) is linear in a dynamic range roughly from 1 to 5×10^3 MIPs; low gain PMT (HAMAMATSU R5325) is linear in a dynamic range roughly from 1000 to $8{\times}10^5$ MIPs. The working voltages of the two PMTs were set at 1400 V in this LED experiment [3]. However, in fact, for YAC experiment, the working voltages of the two PMTs were set at about 1200 V. Therefor, we can conclude that the two PMTs configuration can meet our requirement, that is, YAC might have the wide dynamic range in six orders of magnitude.

2. Probe calibration:

For YAC experiment, the number of charged particles is defined as the PMT output (charge) divided by that of the single-particle peak, which is determined by a probe calibration using cosmic rays, typically single muons. For this purpose, a small scintillator 25 cm × 25 cm × 3.5 cm thick with a PMT (H1949) is put on the top of each YAC detector during the maintenance period as shown in Fig. 4. This is called a probe detector and a coincidence measurement is made. Fig. 5 shows the charge distribution of R4125 by cosmic muons, the peak is defined as one MIP.

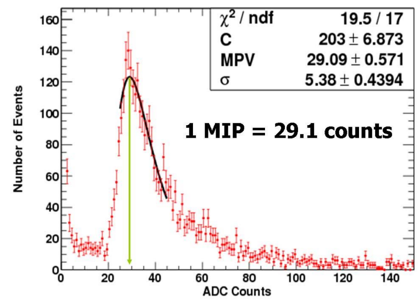

Figure 5: Charge distribution of single muons in a YAC detector. The peak is defined as one MIP. The resolution of ADC count is 0.25 pC/count.

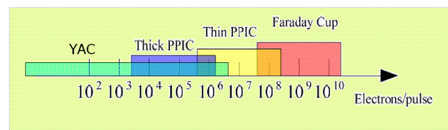

Figure 6: Experimental principle of electron beam calibration of YAC.

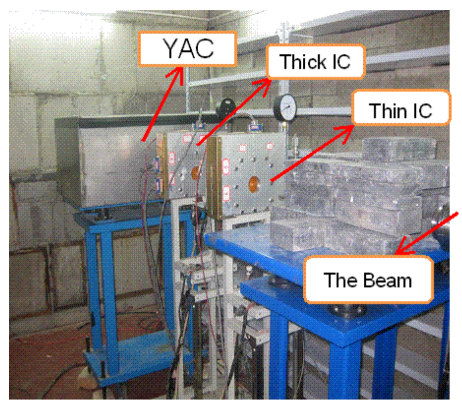

Figure 7: Electron beam calibration of YAC. From right to left, there are the beam, thick IC, thin IC and YAC scintillation counter.

3. Electron beam calibration of YAC:

A measurement of the saturation effect of the plastic scintillator used in the YAC detector was carried out by making use of the electron beam provided by the beam facility of BEPCII (Beijing Electron Positron Collider, IHEP, China). The locations of the detectors and the beam tube close to the detectors are presented in Fig. 6 and Fig. 7, respectively. The electron beam energy is 1.89 GeV. The beam intensity usually is about 10^9 electrons / pulse, which could be attenuated to a range roughly from 10^4 to 4×10^6 electrons /pulse by using a scraper and some focusing magnets to adapt our requirements used in the YAC detector. The beam frequency is 50 Hz with a beam size of about 2 cm^2 and a beam width of 1.2 ns. The beam size near the detectors, measured by a two-dimensional multi-strip ionization chamber (IC), is about 3 cm^2. The beam intensities were measured using a Faraday cup (FC) designed to monitor the beam intensities above 10^8 electrons / pulse, a thick two-dimensional multi-strip IC (thick IC) designed to monitor the beam intensities from 10^5 to 5 $\times10^8$ electrons / pulse, a thin two dimensional multi-strip IC (thin IC) designed to monitor the beam intensities from 10^2 to 5 $\times10^5$ electrons / pulse.

YAC scintillator packaged in a dark stainless-steel box was placed parallel to the ICs and perpendicular to the direction of the beam used. The arrangement of the detectors is presented in Fig. 7. From right to left, there are the beam, thick IC, thin IC and YAC scintillation counter. Using two different gain PMTs, HAMAMATSU R5325 with a low gain and HAMAMATSU R4125 with a high gain, for measuring the light output of the YAC scintillator, our aim is to see whether the YAC detector is possible to have a full dynamic range, from 1 to 10^6 MIPs. To adapt high beam intensities, the attenuator with different attenuation ratios was used in the readout system for both HAMAMATSU R5325 and HAMAMATSU R4125.

When the saturation effect of the YAC scintillation counter appears it mainly consists of two parts. One is from PMT, another one is from the plastic scintillator. To investigate the saturation effect of the plastic scintillator, the linearities of the two selected PMTs were firstly investigated as shown in Fig. 3. Since we found two PMT have the wide dynamic range in six orders of magnitude from Fig. 3, so it can be concluded that the saturation effect of the detector seen in the investigated beam intensity region comes from the plastic scintillator.

The high beam intensity part, near 10^6 electron / (cm^2s), was highly taken into account in this experiment. In this case, high gain PMT HAMAMATSU R4125 could not be used. The signal from the plastic scintillation counter was obtained with low gain PMT HAMAMATSU R5325. The resultant ADC output versus beam intensity in our beam test calibration is shown in Figure 3, within the experimental errors, there is a good linearity between the incident particle flux and YAC-ADC output below 5×10^6 MIPs and the saturation effect of the plastic scintillator appears above it which satisfies YAC detector's requirement. The working voltage of the PMTs was set at 1800 V in this accelerator-beam experiment.

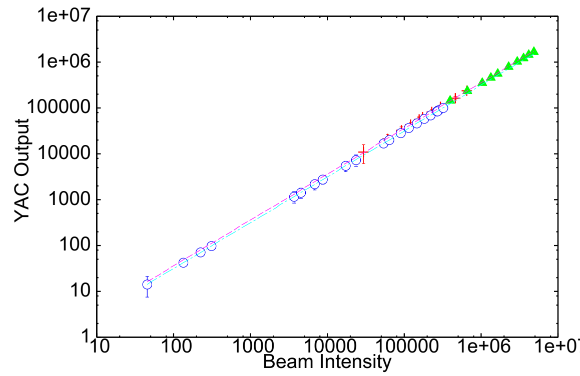

Figure 8: The saturation effect of the YAC. This figure shows that, within the experimental errors, there is a good linearity between the incident particle flux and YAC-ADC output below 5×10^6 MIPs.

4 Conclusion

The accelerator-beam experiment shows a good linearity between the incident particle flux and YAC-ADC output below 5×10^6 MIPs and the saturation effect of the plastic scintillator satisfies YAC detector's requirement. It is a strong support for the work to build an air-shower core detector array near the center of Tibet-III array to study the primary mass composition of CRs around the knee energy region.

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References

[1] M. Amenomori et al., ApJ., 678:1165-1179, 2008.
[2] M. Shibata, Y. Katayose, J. Huang, and D. Chen, ApJ., 716, 1076C1083, 2010.
[3] Y. Katayose, et al., in Proc.29th Int. Cosmic Ray Conf.(Pune), 2005.