

# Development of YAC (Yangbajing Air shower Core array) for a new EAS hybrid Experiment

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**Abstract.** Aiming at the observation of cosmic-ray chemical composition at the knee energy region, we started to develop a new type air-shower-core detector (YAC, Yangbajing Air shower Core array) that will be set up at Yangbajing, 4300m a.s.l. in Tibet, China. YAC will work together with the Tibet-III array 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 can be measured from 1 MIP (Minimum Ionization Particles) to  $10^6$  MIPs. The first phase of this experiment, called "YAC-I", consists of 16 YAC detectors each having the size 40 cm  $\times$  50 cm and distributing in a grid with an effective area 10 m<sup>2</sup>. YAC-I is used to check hadronic interaction models. In the present paper the performance of YAC-I is presented.

**Keywords:** air shower, hadronic interaction, cosmic rays

## I. INTRODUCTION

Until now, all the measurements have showed that the cosmic-ray all-particle energy spectrum can be expressed by a power-law from about  $10^{10}$  to  $10^{20}$  eV with a slight change of slopes between  $10^{15}$  and  $10^{16}$  eV which is called the "knee"[1]. The chemical composition of primary cosmic rays at the knee energy region is of essential importance to understand the origin of high energy cosmic rays. However, the chemical composition in this energy region cannot be observed directly by instruments on board satellites or balloons for their low flux. In addition, most indirect measurements have produced different conclusions on the composition[2]. Therefore, a further improvement of the knee composition study is still necessary. It is known that, when observing ASs at high altitudes, much more high energy particles exist in the core region for which the energy distribution, number distribution, lateral distribution and so on are sensitive to the cosmic-ray composition. Thus we designed a new AS core detector array – YAC, to detect the high energy electromagnetic component of the air-shower cores at Yangbajing, Tibet, mainly for the measurement of spectra of some single elements (p, He, Fe) in the knee region.

On the other side, to interpret experimental data from indirect AS observation, Monte Carlo simulation which depends on the hadronic interaction models is inevitable. Until now, conclusions on the chemical composition by indirect measurement have shown more or less interaction model dependences[3]. Since our YAC will be developed step by step, from a smaller array to a bigger one, our working energy region will also be changed from lower energies to higher ones. As the first step, called YAC-I, only 16 detector units were constructed. Therefore, we set the physics goal of YAC-I at the checking of the hadronic interaction models at  $\sim 10$ TeV energy region. For this purpose we should place the detector units as densely as possible to detect the cores of ASs mostly produced by protons which are the bulk of cosmic rays in the corresponding energies. In the second phase "YAC-II" and the third phase "YAC-III" which will be launched out in the near future we will move to study the cosmic-ray composition around the knee energy region.

In all the three phases YAC will be running together with Tibet-III as a hybrid experiment. While the YAC observes the air-shower core, the Tibet-III obtains the direction and total energy of the shower produced by a primary cosmic-ray particle. In present paper, the design of YAC-I, its performance and the test for a further development are described.

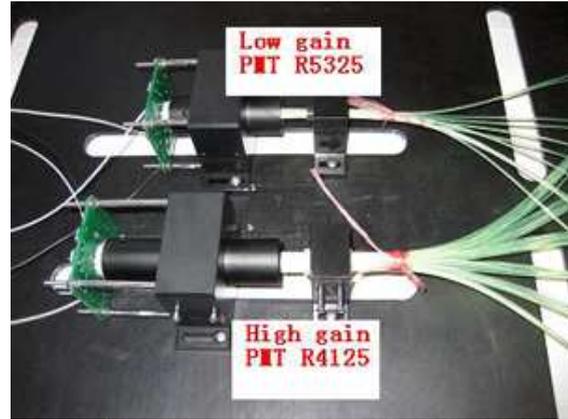
## II. DETECTOR

The design of YAC-I detector essentially followed that described in [4] but some improvements were adapted:

(1) For the energy measurement of high energy electromagnetic particles a lead layer is used to convert them to shower electrons. The energy scope of electrons and gamma-rays in AS cores that we are interested in ranges from  $\sim$ GeV to  $\sim$ 10TeV. By an optimization calculation a lead layer of thickness 3.5 cm suits the measurements in both lower energies and higher energies. The scintillation light produced by shower electrons in the scintillator below the lead layer is transmitted via the wave length shifting fibers (WLSF BCF-92, SAINT-GOBAIN, round cross section with 1.5 mm diameter) to the photomultiplier (PMT).



(a) The outlook of YAC detector.



(b) The wave length shifting fibers (WLSF) and two type PMTs.

Fig. 1. The scintillation counter unit consists of ten scintillators whose size is  $50\text{ cm} \times 4\text{ cm} \times 1\text{ cm}$  and light-isolated from each other using reflecting material. All the fibers is in the same length of  $95\text{ cm}$ . While 10 fibers installed in the scintillators attached to the PMT R5325, the other 40 fibers attached to PMT R4125 are inlaid in the surface of the scintillators with equal distance.

(2) In order to record the electromagnetic showers of energies from  $^*\text{GeV}$  to  $^*10\text{TeV}$ , a wide dynamic range from  $10^1$  to  $10^6$  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  $10^0$  to  $10^6$ . 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  $1-3 \times 10^3$  and  $10^3 - 10^6$ , respectively.

(3) In order to have a certain position resolution of high energy particles in the AS cores  $40\text{ cm} \times 50\text{ cm}$  ( $0.2\text{ m}^2$ ) is taken as the size of a detector unit. One unit scintillation counter consists of ten scintillators with size of  $50\text{ cm}$  in length,  $4\text{ cm}$  in width and  $1\text{ cm}$  in thickness. In order to reach a better uniformity of light output when a high energy particle hits different position of a scintillation counter unit 40 WLSFs are inlaid parallelly on the surface and connected to R4125 while 10 WLSFs installed in the center of each scintillator are connected to R5325.

(4) To save fibers, a short length ( $95\text{ cm}$ , half of the fiber length used in the old detectors [4]) of fiber is used for which one end is connected with the PMT and another end is plated with aluminum for the reflection. Because of that the reflection rate reaches 99% and what we recoded from the detectors is PMT gain only, there is no influence on the experimental data. Considering the large temperature difference in Yangbajing within one year even one day a heat-insulator layer is used inside each detector unit box. Shown in Fig.1 is a detector unit.

The 16 detector units of YAC-I are arranged as a  $4 \times 4$  array. The distance between two units is  $28\text{ cm}$  in the  $X$  direction, and  $18\text{ cm}$  in the  $Y$  direction, while the  $X$  direction is the direction of the scintillator in length of

$50\text{ cm}$ , the  $Y$  direction is the direction of the scintillator in length of  $40\text{ cm}$ . The YAC is placed matching with Tibet-III whose detectors are positioned using GPS.

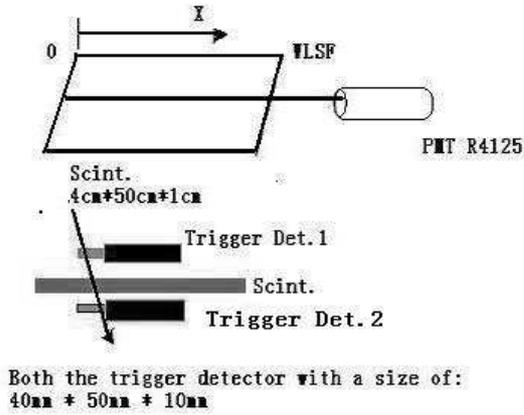
### III. PERFORMANCE MEASUREMENT OF YAC-I

**Linearity of PMTs.** For every PMT (high gain and low gain) used in YAC-I the linearity is measured using LED light source and optical filters. In the test we fixed the positions of LED, filter and PMT. By using different filters we get light of different intensity. The LED is driven by TTL pulse with the width of  $25\text{ nsec}$ . [4]

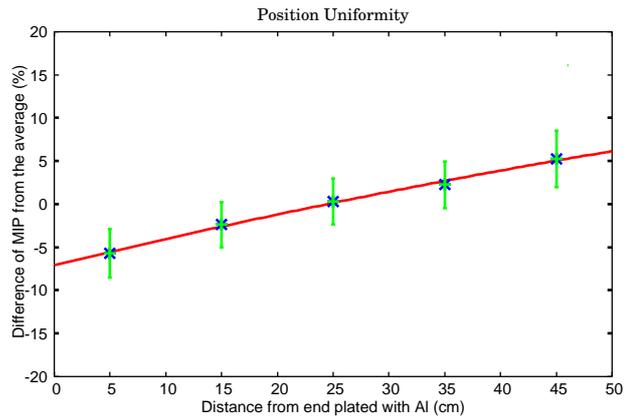
**Uniformity of the detector.** When the charged particles passed through the scintillator in different position, the light transmitted to the PMT by the WLSFs will vary in a little range which is called "position dependence" or "uniformity" of the detector. The position dependence of YAC detector has been measured using cosmic-ray single-muon selected by a triple coincidence as shown in Fig.2(a). Fig.2(b) shows that the uniformity in the scintillator length  $50\text{ cm}$  is better then 6%.

**Linearity of PMT plus scintillator.** With a probe detector ( $25\text{ cm} \times 25\text{ cm}$ ) placed on the top of each YAC detector unit using cosmic-ray single-muon the charge distribution is measured (Fig.3). The single particle peak for which the ADC value corresponds to a minimum ionization particle (MIP) is obtained. To learn more on the linearity of PMT plus scintillator an accelerator beam test was implemented and the result will be reported elsewhere.

**Consistency of the gains of different detector units.** Setting a lower detection threshold (say, taking  $10\text{ mV}$  as the discrimination threshold that roughly corresponds 12 MIPs) and 'any 1' (means that at least any one unit of the 16 units fires) as the trigger condition, we let YAC-I runs one day to measure the burst size

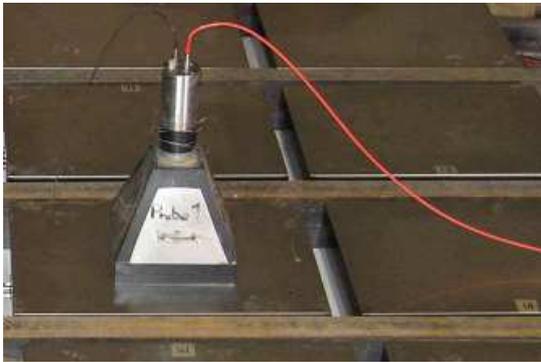


(a) Experiment set-up for muon measurement (MIP)

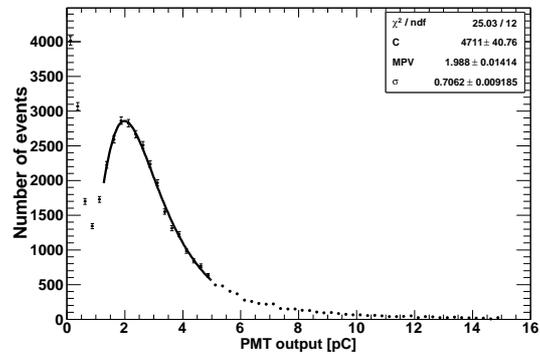


(b) Uniformity measurement

Fig. 2. Single-muon measurement and the uniformity of detector



(a) The probe calibration. On the center of YAC detector is the probe detector whose scintillator is size of 25 cm × 25 cm × 3.5 cm with a PMT(H1949)



(b) Charge distribution of a single-muon in a detector unit. The peak is defined as one MIP.

Fig. 3. The probe calibration and charge distribution of single-muon

spectrum of each detector unit. Some differences are found from the burst size spectrum of each unit. By slightly adjusting the working voltage of high gain PMT consistent spectra are obtained. Fig.4 shows that the systematic error of each detector is smaller than 3%.

The correlation between high gain PMT R4125 and low gain PMT R5325. For we can not measure the single-muon of low gain PMT R5325 directly, we calculated it from the correlation between high gain PMT R4125 and low gain PMT R5325. After the detectors running consistently for a week, we get the gains of PMT R5325 and R4125 of the same burst events which are recoded by ADC as shown in Fig.5. Then we can obtain the ratio (just the slope of the line in Fig.5) between PMT R5325 gain and R4125 gain. With further calculation we can get the burst size read out by the low gain PMT.

Then YAC-1 started the data taking from the April of

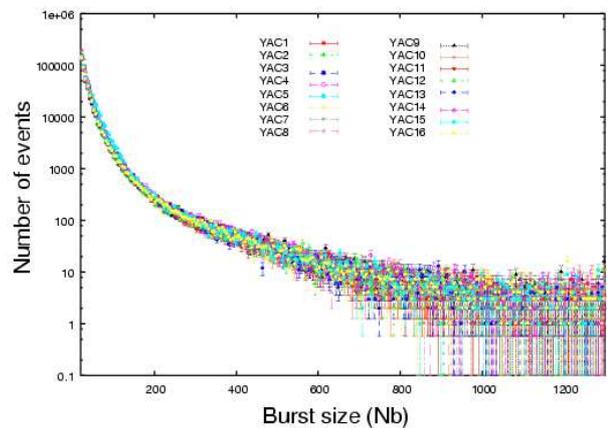


Fig. 4. The burst size spectrum which shows the systematic error of each detector is smaller than 3%.

2009 at the trigger condition: at least anyone unit is fired with burst size larger than 12. The event rate is 30Hz with dead time 13%.

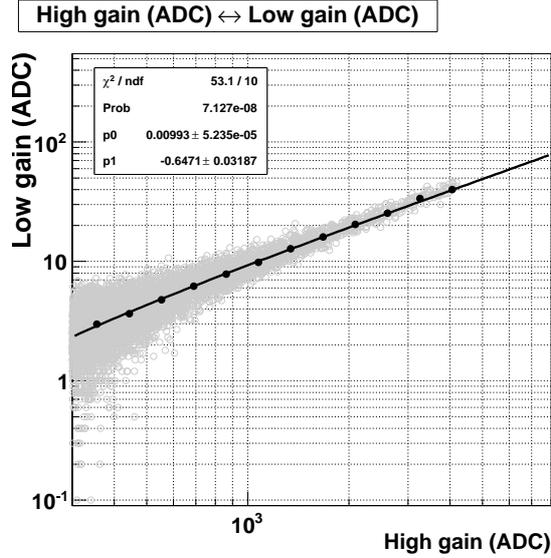


Fig. 5. The correlation between high gain PMT and low gain PMT

#### IV. TEST EXPERIMENTS

It is known that using optical cement or optical grease to couple the scintillator and the fiber can significantly increase the light collection of PMT. However, whether it works well under the Tibet weather conditions is an unknown factor. For the next step of YAC a test experiment that optical cement and optical grease are used in several scintillators is also set up and running in Yangbajing.

Together with this we did another test to use the old L3C scintillators which are expected to be used in the next experiment. The thickness of L3C scintillator is 2 cm and there is optical cement between fibers and scintillation counter. This test is important to check the optical property of cement used many years ago. Both the two tests will last running about one year.

#### V. SUMMARY

Sixteen air shower core detectors (YAC-I) were set up in YBJ and started data taking from the April of 2009. Each YAC consists of 0.2 m<sup>2</sup> plastic scintillator, a high gain PMT and a low gain PMT, covered with 3.5 cm Pb plate. The dynamic range is from 1 MIP to 10<sup>6</sup> MIPs. Using the trigger conditions: at least anyone YAC fired by  $N_b \geq 12$  MIPs, the event rate reaches 30Hz with dead time of 13%.

A study of Monte Carlo simulation shows that it is feasible to check the hadronic interaction models using such a mini YAC array [5,6].

#### VI. ACKNOWLEDGMENT

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