

LHAASO Simulation: Sensitivity on Gamma Ray Sources above 30 TeV

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Abstract. Fine measurement of gamma ray energy spectra above 30TeV is crucial to identify sources as galactic cosmic ray accelerators. As a part of the Large High Altitude Air Shower Observatory (LHAASO) project at YBJ, Tibet, China, a 1km² extensive air shower array (KM2A) is proposed, equipped with 43,000m² muon detectors. Monte Carlo simulation shows that primary gamma showers can be identified event by event using muon content. The observation is background free above 50TeV. With a sensitivity of about 1% I_{Crab} , high duty cycle of at least 90% and full sky survey, the array would be very useful in discovering galactic gamma ray sources and identifying cosmic ray sources.

Keywords: Sensitivity, Simulation, Gamma Ray Source

I. INTRODUCTION

About 80 sources above 1TeV are identified by ground based cosmic ray experiments so far[1]. we know some of TeV sources have hard spectrum, A few of them showed observational evidences of being universe accelerators with cosmic rays being accelerated. Although SNRs are theoretically considered to be the most plausible candidates for acceleration of cosmic-ray hadrons up to PeV energies, no observations have succeeded in identifying them by now. Since accelerated electrons have difficulty producing very high-energy gamma rays with energies above 100 TeV via bremsstrahlung or inverse Compton scattering, it can be an effective way of obtaining clear evidence for hadronic acceleration to detect high-energy gamma rays above 100 TeV generating via the decay of neutral pions produced in interactions of accelerated hadrons with ambient material, e.g. molecular clouds. In other words, studying on energy-dependent morphology of sources in the 10-1000 TeV region is a clue to disentangle their acceleration mechanism. This is going to be conformed in the future experiments with more concrete evidences.

There are two successfully operating experiments at Yangbajing Cosmic Ray Observatory (90° 31E, 30° 06N; 4,300 m a.s.l., in Tibet, China): $AS\gamma$ array and full coverage YBJ-ARGO experiment. The limited angular resolution and lack of primary particle identification result in a lower sensitivity performance comparing with the Cherenkov telescope arrays at the same energies. A new project named LHAASO (Large High Altitude Air Shower Observatory) is proposed for discovering

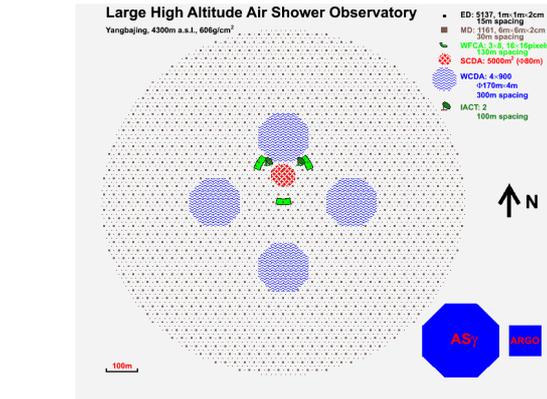


Fig. 1: Layout of the LHAASO project. KM2A : black dots represent 1m² scintillation charged particle detectors (ED) on the ground. Squares represent muon detectors (MD).

galactic gamma ray sources and identifying cosmic ray sources at 10-1000TeV energy region. KM2A, one of main parts of LHAASO, is a full duty cycle array including Electron Detector (ED) array with about 43,000m² Muon Detectors (MD). It aims at: Detecting gamma rays above 30TeV from sources with high performance on particle discrimination.

II. THE FUTURE PROJECT:LHAASO

The currently proposed configuration of the LHAASO project is shown in Fig.1. There are three major components of detectors. One is a scintillator charged particle counter array covering an area of 1km²(KM2A). Two major detectors are included in KM2A. EDs are to sample Electrons and photons in a shower with 1m² counters, 5100 of them are located in an equilateral triangular grid with a side length of 15m. MDs are 1200 dirt buried 6 × 6m² counters, they are also located in an equilateral triangular grid and the side length of them is 30m. Each ED is covered by one 0.5cm thick Pb plate used as gamma converter to increase number of electrons for improvement of angular resolution and position resolution. Each MD is covered by overburden of 2.8m thick earth to remove electro-magnetic parts in a shower, therefore muon energy threshold is 1.3GeV.

Another component of LHAASO are water Cherenkov detectors array (WCDA) composed of 4 water pools and 22,500m² each. The third major component are

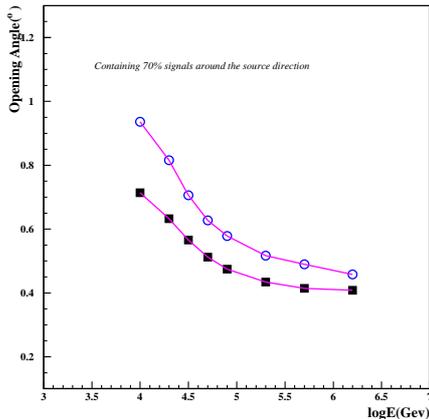


Fig. 2: Opening angle including 70% signals as a function of primary energy of showers. Circles are results of proton and the solid black boxes are of photon.

two Imaging Cherenkov Telescopes (ICTs) similar to the Magic experiment. The detailed introduction about them please refer other work about LHAASO project in this conference[2][3][?][?]. In this work, we study on LHAASO sensitivity on gamma ray sources with MC simulation data only considering the contribution from KM2A.

III. MC SIMULATION

The air shower events induced by primary cosmic rays and gamma rays were generated by the Corsika Ver.6.6001 code. Primary energy of particles is sampled from a power law spectrum between 10TeV to 10PeV and arrival direction is sampled from a isotropic distribution in a range of zenith angle less than 45° and azimuth angle from 0 to 2π . Along the Crab's orbit, We using a differential energy spectrum index -2.5 for the primary photons, but for Protons, the index of energy spectrum is -2.7 at the energy range from 10TeV to 100TeV and -2.74 at the range from 100TeV to 10PeV considering the "knee" case. KM2A's response was simulated using the Code established by ourselves that give the responding information of each detectors according to the different showers. Some detector's physical proceedings are taken into account by parametrization value. Procedure of data analysis is as follows: A shower Front has a conical shape reconstructed from positions and arrival time in hit EDs, and it is fitted in least square method to gain EAS direction. EAS core position, size and age can be reconstructed from electrons in EDs by fitting lateral distribution with the NKG function [4][5] in maximum likelihood method. Position of weight center of electron hits is used as initial value of the core position, and several iterations of both direction and lateral distribution reconstruction are proceeded to obtain optimized direction, core position, size and age. At the same time, count hits on MDs for the muon content for

each shower.

We selected "good" events based on the following conditions:

- 1) Reconstructed zenith angle lower than 45° ;
- 2) Triggred Number of EDs larger than 20;
- 3) Shower core location within 500m from the center of the array.

These selections are sufficient to collect the air shower events that actually trigger the ED array. In addition, they are favorable conditions for getting rid of the low-muon hadrons showers merged into photons, that means it will optimize the primary events discrimination.

Fig.2 shows KM2A's angular resolution with above selections. In Fig.2, the value is got from the distribution of space angle between the primary dropping directions and reconstructed directions, within the opening angle radius including about 70% events. It shows that KM2A's angular resolution is better than 0.5° for gamma ray above 30 TeV energy. The resolution of *gamma* is better than that of *proton* due to the secondary particle of gamma-induced showers is more regular.

IV. SIGNIFICANCE CALCULATION

We use the following equation for calculating the significance to crab-like sources

$$S(\geq N_{hit}) = \frac{N_\gamma(\geq N_{hit})}{\sqrt{N_{bkg}(\geq N_{hit})}} \quad (1)$$

$$= \frac{\int_E A_{eff}^\gamma(E) J_\gamma(E) dE \cdot \varepsilon_\gamma(\Delta\Omega) \cdot T(s)}{\int A_{eff}^{CR}(E) J_{CR}(E) dE \cdot \Delta\Omega(N_{hit}) \cdot T(s)} \cdot Q \quad (2)$$

Here A_{eff} is effective area, it is a function of primary energy for different particles. We take $J_\gamma = 2.86 \times 10^{-11} \cdot E^{-2.67} \cdot cm^{-2} \cdot s^{-1} \cdot TeV^{-1}$ as Crab Nebula differential spectrum, measured by the HESS collaboration[6]. And the cosmic Ray differential spectrum $J_{CR} = 1.43 \times 10^{-5} \cdot E^{-2.7} \cdot cm^{-2} \cdot Sr^{-1} \cdot s^{-1} \cdot TeV^{-1}$ getting from [7]. ε means the percentage of signals within opening angle pointing source direction, as mentioned above, here $\varepsilon = 70\%$. The crab walking time in LHAASO field of view is about 6.53 hours per day within 45° zenith angle, so during a calendar year's observation, the observation time T(s) calculated with the value $365 \times 6.53 \times 3600$ in second unit. Q is the factor for γ/p discrimination.

Fig.3 shows the distribution of μ contents for different primary showers. Red curve is of gamma induced showers and blue is of proton induced showers, here we take above-30-TeV events as an example for showing.

Fig 4 is an example (We also selected events that energy above 30TeV.) showing the gamma-induced showers and proton-induced showers Muon content and

TABLE I: In one calendar year's observation KM2A will detect gamma signals and background events within the opening angle, the below listed E_γ^m means the mode energy for each N_{hit} bin, and survival means after cut-line selecting remained composition. BF means background free.

N_{hit} bin	E_γ^m (TeV)	opening angle(°)	$N_\gamma(\geq E_\gamma^m)$	survival γ s(%)	$N_{CR}(\geq E_\gamma^m)$	survival CRs (%)	$S(\sigma)$
100-110	12.6	0.63	23829	34.31	5655368	0.0139	291
110-120	16.0	0.62	16545	34.31	3782833	0.0103	288
120-130	19.0	0.60	11248	33.17	2466015	0.0070	283
130-150	23.0	0.58	8562	33.63	1748691	0.0045	324
150-190	30.0	0.56	6272	35.07	1206158	0.0043	305
190-220	41.0	0.53	4056	35.11	704618	0.0015	438
220-250	50.0	0.50	2426	37.73	369808	0.0007	569
250-300	60.0	0.49	1747	40.43	249381	0.0010	447
300-500	84.0	0.48	1289	45.25	174837	BF	
500-1000	160.0	0.47	733	48.81	93711	BF	
1000	240.0	0.45	250	76.32	29257	BF	

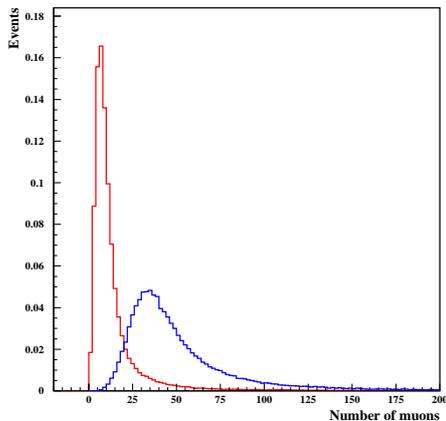


Fig. 3: Number of muons distribution. Red curve is of gamma induced showers and blue is of p induced showers.

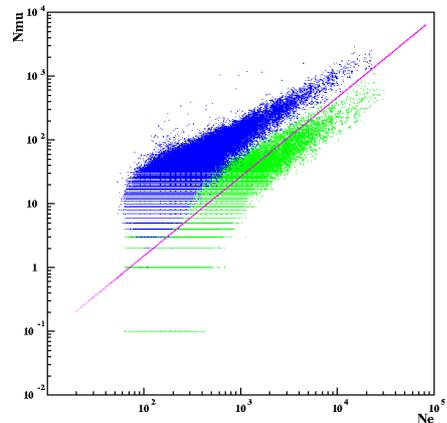


Fig. 4: Distribution of N_μ as a function of N_e in a same shower. Green and blue dots correspond to gamma-induced and p-induced air shower events, respectively.

electrons as veto signals for hadronic showers. And the red solid-line is for optimizing Q factor, in different energy bins we selected different cut-lines to get rid of most of hadron backgrounds. At higher energies region, hadronic showers as the background have sufficiently large muon content contrast with gamma showers that serves as a enough clean veto signal for suppression of the background. Fig4 illustrated how well this can be fulfilled. The large scale muon detector array of the KM2A will reject the hadronic shower background at a level of 10^{-5} or even better at above 50 TeV region. This essentially enable creating background free gamma

rays samples for high energy sources. It forms a base for highest sensitivity for the high energy gamma ray sources discovery.

V. SENSITIVITY RESULTS

we divided the events into 11 bins in accordance with the number of hits (N_{hit}) detected by the EDs array. Here N_{hit} of the shower is correlated with event primary energy, and can be used to evaluate the energy with 30% resolution(refer Fig. 5). We calculate the significance with optimized cut conditions, the survival gammas and CRs are listed in the Table.1.

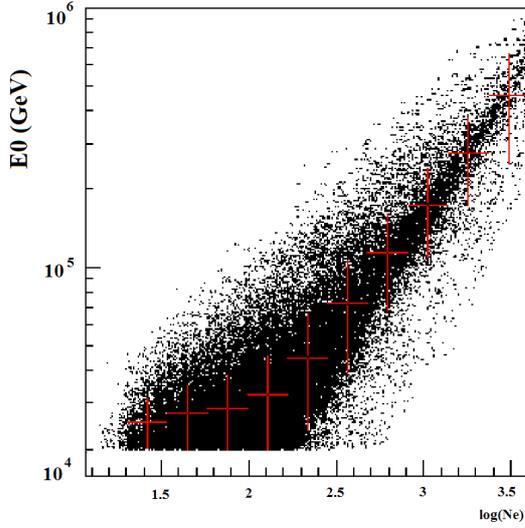


Fig. 5: Number of electrons correlated with primary energy (E_0) for gamma induced showers.

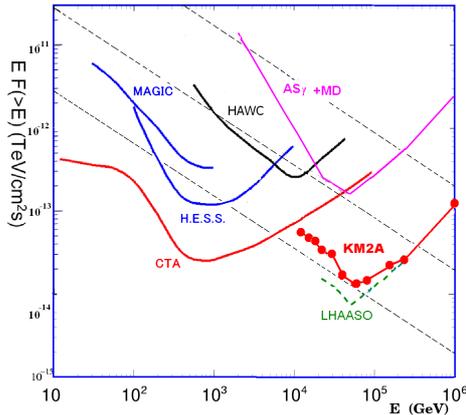


Fig. 6: The KM2As integral flux sensitivity (5σ in one calendar year) to a crab-like gamma-ray source, together with the sensitivity of some other experiments or future proposals. The red dots chained by the red lines is results from this work.

Q factor as a measurement of enhancement in sensitivity has a strong dependence of the shower energy. The better discrimination power will be obtained at the higher energy. For instance, the Q factor can be as large as 54 above 30 TeV. Results listed in Table 1. show the survival efficiency of the air shower events after cutting, obtained from the simulation. Its 5σ sensitivity in one calendar year will reach less than 1% Crab above 50 TeV. Here we named BF as background free points. At these BF points we take 10 events per year as a standard to estimate the sensitivity. Fig.6 shows the KM2As integral flux sensitivity to a crab-like gamma-ray source together with the sensitivity of some other experiments or future proposals.

VI. DISCUSSIONS AND SUMMARY

It should be mentioned that in our simulation we have not taken the WCDA as a muon detector array into account yet in estimate of. Further improvement of performance of the LHAASO/KM2A would be expected by using WCDA. While a detailed simulation is undergoing, we have estimated the sensitivity in the most optimistic case, i.e. the WCDA serves as a perfect muon detector array namely every muon falling to the detector will be identified without ambiguity. It is represented by dashed line in Fig. 5. Eventually, a more realistic sensitivity of the LHAASO detector will in between the two extreme cases.

According to our simulation, the LHAASO project has sufficient ability to observe above 30 TeV region gamma rays and discovery new sources. It has the ability to observe gamma-ray acceleration limits on the sources in the sub-hundreds TeV region, and it will contribute to a deeper understanding of the origin and the acceleration mechanism of cosmic rays in cooperation with other experiments.

VII. ACKNOWLEDGEMENT

This work is supported by Knowledge Innovation fund (H85451D0U2) of IHEP, China.

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