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LHAASO-KM2A simulation

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Abstract: At Yangbajing, with altitude of 4300m a.s.l., the LHAASO site is an ideal location for energy spectrum and composition measurements for cosmic rays, including gamma rays, above 30TeV because developing maxima of air showers are 1-2km above the ground. One main part of LHAASO (The Large High Altitude Air Shower Observatory) project, KM2A, using a $1km^2$ array composed of electron detectors(ED) and muon detectors(MD), focuses on gamma ray astronomy above 30TeV and cosmic ray physics in the "knee" region. Fine measurement of gamma ray energy spectra above 30TeV is crucial to identify sources as galactic cosmic ray accelerators. 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. A simulation is carried out for optimizing performance of the KM2A array, mainly in gamma ray astronomy above 30TeV . Moreover, compared with the report at the last ICRC, the present one considers more details of detector parameterizations and improves analysis.

Keywords: LHAASO, KM2A, gamma ray astronomy, optimization

1 introduction

Cosmic particle accelerators are believed to accelerate primarily charged particles, such as electrons and ions, by acting on these particles with electric fields or magnetic fields. High-energy gamma rays are almost always secondary products of the cosmic accelerators. When a proton accelerated in the supernova blast wave interacts with nuclei of the ambient medium, generating new particles in the collision, among them π_0, which decay into two gamma rays. If the primary accelerator generates a beam of high-energy electrons, these electrons may undergo bremsstrahlung in the ambient medium, may suffer synchrotron radiation losses in local magnetic fields,or may, via the inverse Compton scattering process, transfer a significant part of their energy to an ambient photon, which then emerges as a high-energy gamma ray. Compared to the charged particles, which are the primary products of cosmic accelerators, gamma-rays have the substantial advantage that they propagate on straight lines through the universe. Gamma-rays detected on earth point back towards their sources and can be used to locate and study the sources. Recent discoveries in this waveband have important consequences for a wide range of topics in astrophysics and astroparticle physics. More than 120 TeV sources are identified by ground based cosmic ray experiments so far[1]. All of them are seperated into some types of acceleration sites such as : Supernova,Pulsars and pulsar nebulae, Binary stars, Giant molecular clouds, Black holes in the centers of active galaxies, Starburst galaxies,Clusters of galaxies,Extra-galactic pair halos and Relics of the Big Bang[2]. 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. This is going to be conformed in the future experiments with more concrete evidences.

Yangbajing, with altitude of 4300m a.s.l., is an ideal location for high energy gamma ray astronomy and cosmic ray physics in the knee region, since the altitude is close to the maximum of EAS development in such energy region. At Yangbajing, there have been two experiments for these targets, ARGO-YBJ [9] with RPC target array and Tibet-ASγ [**?**] with electron array and burst detectors for EAS cores. At present, LHAASO , a next generation project, is proposed to study particle astrophysics at Yangbajing [11]. LHAASO is a hybrid detection with a huge covered and sensitive area, composed of 1km^2 array(KM2A), 90000m^2 water Cherenkov detector array, 28 wide field Cherenkov telescopes, and 5000m^2 shower core detectors(SCDA).

One main part of LHAASO project, KM2A, using a $1km^2$ array composed of electron detectors(ED) and muon detectors(MD), focuses on gamma ray astronomy above 30TeV and cosmic ray physics in the "knee" region. So called standard configurationof KM2A is as following: ED, with sensitive area of 5000m2, consists of 5000 plastic scintilators with size of 1mx1mx2cm, placed in triangle with distance of 15m. Each ED is covered by one 0.5cm Pb plate used as γ converter to increase efficiency for improvement of angular resolution and position resolution. MD, with sensitive area of 43200m2, consists of 1200 plastic scintilators with size of 6mx6m, placed in triangle with distance of 30m. Each MD is covered by overburden of 2.8m dirt, which has muon energy threshold is 1.3GeV, to mask electro-magnetic particles in a shower contribution. A simulation was reported in the last ICRC for performance of the KM2A array in gamma ray source search [12] and in cosmic ray energy spectrum and composition in the "knee" region [13]. In this report, a simulation is carried out for optimizing performance of the KM2A array, mainly in gamma ray astronomy above 30TeV .

2 KM2A simulation

In KM2A simulation program , response of an unit detector is carried out based on a parametrization input. Simulation of ED γ converter and MD overburden is made individually with GEANT4 [15] described in [13]. Besides of it, Signal pulse is referred to one measured at the KM2A engineering array, which is a negative pulse with rise time 5ns, fall time 30ns and height sampled randomly as Landau distribution. For one single charged particle, mean value of Landau distribution is 10 photoelectrons and maximum probability value is 2.5 photoelectrons. Pulse height threshold is 7 photoelectrons. Trigger is set as any 20 ED hits, i.e., Ntrig$>$ 20 in time window 600ns, and readout time window is $10\mu s$. Noise from single cosmic secondaries in ED and MD is 1000Hz/m^2 and 300Hz/m^2 respectively. In order to decrease noise in MD, number of muons in MD is counted in a time window $\pm 30ns$ around the peak time of electrons in ED during offline analysis.

In this simulation, cosmic rays are generated by Corsika [14] version 6.616. The selected hadronic interaction model is QGSJETII-GHEISHA. Primary energy is from 10TeV to 10PeV. Zenith angle is $0-45°$, and azimuthal angle is $0-360°$. Observation level is same as YangBaJing.

Data analysis method has been described in [13]. Besides of it, some improvements was made in analysis. A time window of $\pm 500ns$ is set for Ntrig$<$ 150 in order to reduce noise from single cosmic secondaries in ED. For Ntrig$>$ 150, a space window around core of one shower is set in order to keep symmetric shape with core near boundary of the array. These improvements are beneficial to obtain higher angular resolution and core position resolution.

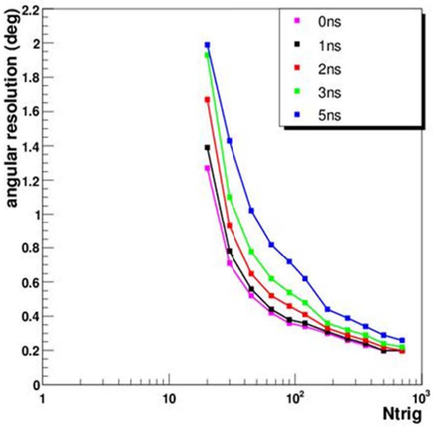

Figure 1: Angular resolution of ED vs Ntrig for different timing resolution.

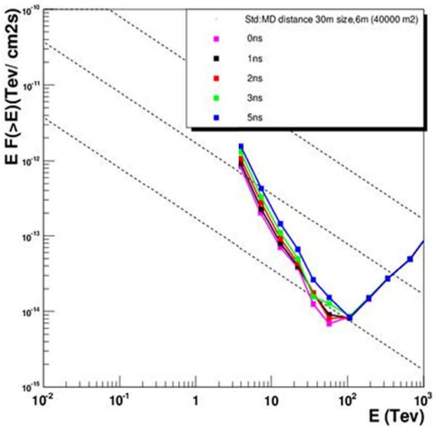

Figure 2: Sensitivity of the KM2A array for different timing resolution.

3 Optimization of KM2A

In order to reach the best performance-price ratio, optimization of KM2A is proceeded as follows. Several configurations are compared with "the standard one".

3.1 Optimization of ED

For ED, two kinds of specification of the detectors are concerned. The first one is timing resolution which is changed into 0ns, 1ns, 2ns, 3ns and 5ns. it indicates that timing resolution is lower, angular resolution is better(Figure 1). Final sensitivity of the array (Figure 2) indicates that timing resolution is lower, sensitivity is better, and sensitivity is closed among 0ns, 1ns and 2ns.

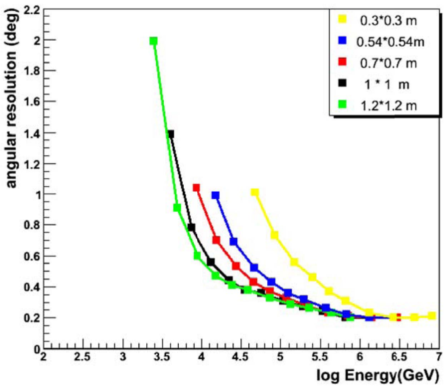

Figure 3: Angular resolution of ED vs Ntrig for different size of unit ED detector.

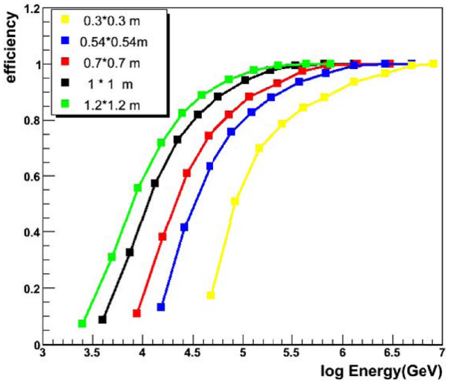

Figure 4: Trigger efficiency for different size of unit ED detector.

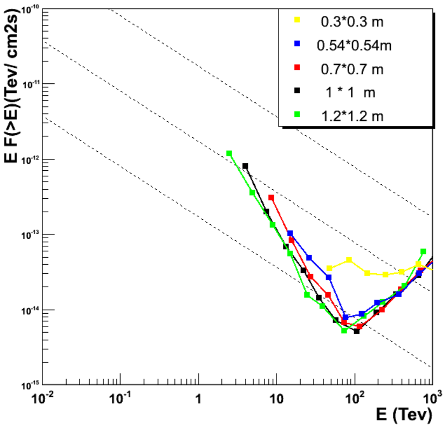

Figure 5: Sensitivity of the KM2A array for different size of unit ED detector.

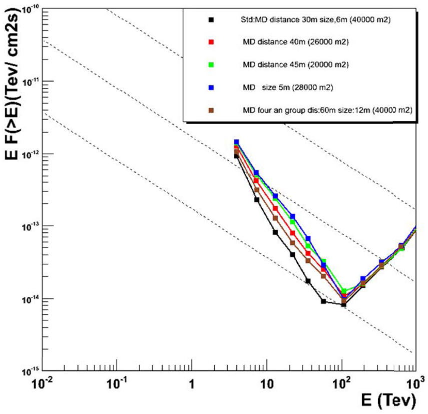

Figure 6: Sensitivity of the KM2A array for different arrangement of MD detectors

The second specification is size of ED detectors which is changed into $0.3m \times 0.3m, 0.54m \times 0.54m, 0.7m \times 0.7m, 1.2m \times 1.2m$, and sensitive area of ED are $500m^2, 1500m^2, 2500m^2, 7200m^2$ respectively. it indicates that size is larger, angular resolution is better(Figure 3), and trigger efficiency is higher (Figure 4) especially at lower energy range. Final sensitivity of the array (Figure 5) indicates that size of detector unit is larger, sensitivity is better, and sensitivity is closed among the standard configuration and $1.2m \times 1.2m$.

3.2 Optimization of MD

For MD, the most important specification is size of unit detectors and amount of detectors which decides how many muons can be obtained. There are four configurations considered, changed from "the standard configuration":

- Distance between detectors increases to 40m, and sensitive area of MD decreases to $26000m^2$;
- Distance between detectors increases to 45m, and sensitive area of MD decreases to $20000m^2$;
- Size of MD is reduced to $5m \times 5m$, , and sensitive area of MD decreases to $28000m^2$;
- Size of MD is enlarged to $12m \times 12m$, and Distance between detectors increases to 60m, therefore sensitive area of MD is not changed;

Final sensitivity of the array (Figure 6) indicates that sensitivity is not only decided by sensitive area of the array, which is that sensitive area is larger, sensitivity is better, but also decided by arrangement of detectors, i.e., separated (the standard one) is better than concentrated (case 4).

4 Sensitivity to Crab-like sources

For KM2A experiment, we can estimate the detected γ signals with

$$N_{\gamma} = \int_{E} A_{eff}^{\gamma}(E) J_{\gamma}(E) dE \cdot \varepsilon_{\gamma}(\Delta\Omega) \cdot T(s) \quad (1)$$

and when collecting the signals , the mixed background events at the same open angle can be calculated by

$$N_{cr} = \int A_{eff}^{CR}(E) J_{CR}(E) dE \cdot \Delta\Omega(N_{trig}) \cdot T(s) \quad (2)$$

A_{eff} means effective area, it is a function of primary energy for different particles and different sources . Here , we just give the results tracking Crab Nebula source as an example. 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[**?**]. 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 [8]. ε means the percentage of signals within opening angle pointing source direction, here we take $\varepsilon = 70\%$ since it is the optimal opening angle of signal to noise ratio. 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. We use LiCMa formula[6] to calculate the significance for the higher statistic background N_{trig} bins

$$S(\geq N_{trig}) = \frac{N_{\gamma}(\geq N_{trig})}{\sqrt{N_{bkg}(\geq N_{trig})}} \cdot Q \quad (3)$$

Q is the factor for γ/p discrimination. As mentioned above, Q can be calculated by

$$Q = \frac{Survival\ Ratio\ of\ \gamma}{\sqrt{Survival\ Ratio\ of\ CR}} \quad (4)$$

5 Conclusion

A simulation is carried out for optimizing performance of the KM2A array, mainly in gamma ray astronomy above 30TeV. The following configurations reach optimization: timing resolution of ED detectors is less than 2ns, size of ED unit detector is $1m \times 1m$ with distance of 15m, and size of MD unit detector is $6m \times 6m$ with distance of 30m. More optimization processes will be performed and more details of simulation will be added in according to test at the engineering array in the near future. we reported the sensitivity's estimation of the future LHAASO-KM2A experiment. The better discrimination power will be obtained at the above 30 TeV region. According to our simulation, with the standard of 5σ significance in one calendar year, the LHAASO project will reach less than 1% Crab above 50 TeV . LHAASO project's advantages in this region and it's ability to observe and discovery new sources are obvious.

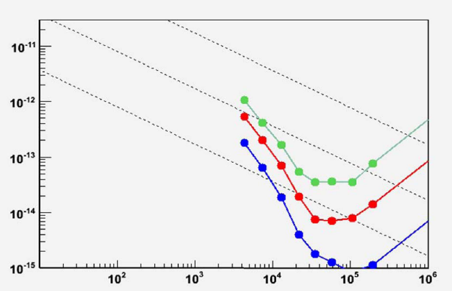

Figure 7: Sensitivity of the KM2A array for different crab-like sources with index 3.0, 2.6, 2.2(from top to bottom).

6 Acknowledgments

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Figure 7 gives Sensitivity of the KM2A array for crab-like sources with different indexes .

References

[1] TeV Sources Catlog on line : http://tevcat.uchicago.edu/
[2] http://www.mpi-hd.mpg.de/hfm/HESS/pages/about/physics/
[3] Z. Cao *et al.* for the LHAASO Collaboration, 31th ICRC, LORZ, (2009)
[4] D. Heck et al., 27th ICRC, Hamburg, 233 (2001)
[5] g4) J. Allison et al., IEEE Transactions on Nuclear Science 53 No. 1 (2006) 270-278.
[6] Li, T. P., & Ma, Y. Q. 1983, **ApJ**, 272, 317
[7] C. Mastersona, et.al for the H.E.S.S. collaboration, in the **Proc. of 29th ICRC**, Pune(2005):101-106
[8] L.P.Ivanenko, et.al, JETP Lettt.: Vol.48.No.9(1988)
[9] M. Iaccovacci for ARGO-YBJ collaboration,, Nuclear Physics B (Proc. Suppl.) 175-176 (2008) 389-394
[10] M. Shibata for Tibet ASgamma Collaboration, Nuclear Physics B (Proc. Suppl.) 175-176 (2008) 267-272
[11] Z. Cao on behalf of the LHAASO collabration, ICRC 2009
[12] S.W. Cui on behalf of the LHAASO collabration, ICRC 2009
[13] X.H. Ma on behalf of the LHAASO collabration, ICRC 2009
[14] D. Heck et al., 27th ICRC, Hamburg, 233 (2001)
[15] J. Allison et al., IEEE Transactions on Nuclear Science 53 No. 1 (2006) 270-278.
[16] K. Greisen, Prog. Cosmic Ray Phys. 3(1956) 1.
[17] K. Kamata and J. Nishimura, Suppl. Prog. Theor.Phys. 6 (1948) 93.