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TOWARDS NEW ANALYSIS OF GAMMA-RAY SOURCES AT HIMALAYAN GAMMA-RAY OBSERVATORY (HIGRO) IN NORTHERN INDIA

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Abstract. The High Altitude GAmma-Ray (HAGAR) array is a wavefront sampling array of 7 telescopes, set-up at Hanle, at 4270 m a.s.l., in the Ladakh region of the Himalayas (North India). It constitutes the first phase of the HImalayan Gamma-Ray Observatory (HIGRO) project. HAGAR is the first array of atmospheric Cherenkov telescopes established at a so high altitude, and was designed to reach a relatively low threshold (currently around 200 GeV) with quite a low mirror area (31 m^2). Data are acquired using the On-source/Off-source tracking mode, and by comparing these sky regions the strength of the gamma-ray signal is estimated. Regular source observations are running since Sept. 2008 and preliminary results on Crab nebula were reported by 2009. Improvements of our analysis method are still going on, like estimation of arrival direction and estimation of night sky background. New softwares are under development for analysis of flash ADC modules, which provide more information from the incoming Cherenkov light wavefront. We report and discuss our new estimation of the systematics through dark region studies, and present new perspectives in the analysis of gamma-ray sources in this paper.

Keywords: gamma rays: atmospheric Cherenkov technique, methods: data analysis, telescopes: HAGAR

1 The HAGAR experiment

Located at 4270 m a.s.l. in the Ladakh region of the Himalayas, in North India (Latitude: 32°46'47" N, Longitude: 78°59'35"E), the HImalayan Gamma-Ray Observatory (HIGRO) was designed to conduct experiments using the Atmospheric Cherenkov Technique (Britto et al. 2010). Operating with the full array of telescopes since 2008, the HAGAR experiment is a the first phase of HIGRO. It is a sampling array of 7 telescopes, each one built with 7 para-axially mounted 0.9 m diameter mirrors. Other characteristics are: f/D ~ 1; fast Photonis UV sensitive PMTs XP 2268B at the focus of each mirror and with a field of view of $3°17'$; data recorded for each event: relative arrival time of shower front at each mirror accurate to 0.25 ns using TDCs; total charge at each mirror recorded using 12 bit QDCs (ADCs); absolute event arrival time accurate to μs; for trigger generation, the 7 pulses of PMTs of a given telescope are linearly added to form telescope pulse, called *royal sum* pulse. HAGAR operates with a trigger logic designed to significantly reject random triggers due to night sky background (NSB), as well as some of the cosmic ray events. Thus, a coincidence of any 4 telescope pulses above a preset threshold out of 7 royal sum pulses within a resolving time of 150 to 300 ns generates a trigger pulse (Chitnis et al. 2009a). Preliminary simulations yield an estimation of the HAGAR energy threshold to be around 200 GeV from vertical showers, before performing analysis cuts on data, for a total experimental trigger rate around 14 Hz. The phase 2 of HIGRO will be the installation of an imaging 21 m diameter telescope MACE (Major Atmosperic Cherenkov Experiment), whose first light is expected in 2012 (Yadav et al. 2009).

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2 Signal extraction procedure

The analysis of HAGAR data is based on the arrival angle estimation of the incident atmospheric shower w.r.t. the source direction. This angle—called space angle—is obtained for each event by measuring relative arrival times of the showers at each telescope. Precise time calibration of the optoelectronic chain is then required, as well as an accurate pointing of telescopes (Chitnis et al. 2009a). The former is achieved first by computing TDC differences between telescopes from fix angle runs where the theoretical time-offsets are computed, using information on the pointing direction, coordinates of telescopes, and on the transit time of each channel through the electronic chain. The TDC differences between telescopes from fix angle runs yield the calculation of what we call "T_0's" (say "t-zeros"), which are the relative time offsets for all telescope to be used in the analysis to ensure a valid estimation of the relative timing differences in the arrival of the Cherenkov signal on the telescopes. Space angle is then computed by fitting the arriving spherical Cherenkov wavefront, using plane front approximation. For each event, the value of the χ^2 of the fit and other fit parameters are given, and the number of telescopes with valid TDC information, *i.e.* participating in the trigger, is written. Thus are defined four types of events, based on the *Number of Triggered Telescopes* (NTT), viz. events with NTT=4, NTT=5, NTT=6 and NTT=7.

In order to remove isotropic emission due to cosmic rays, source observation region (ON) is compared with OFF-source region at same local coordinates on the sky, but at a different time (before or after tracking the source region for about 30-50 mins). Atmospheric conditions change during observation time, reflected by variations on the trigger rate readings. This add systematics in our analysis. Normalisation of background events of both the ON and OFF source data sets is done by comparing number of events at large space angles, where no gamma-ray signal is expected. This yield a ratio, called normalisation constant, which allows to calculate the ON-OFF excess below one specific cut on the space angle distribution. More on the descrition of the analysis method and data selection can be found in Britto et al. (2009b).

3 Preliminary analysis of HAGAR data

Crab nebula, standard candle of the γ-ray astronomy, is used to calibrate the instrument and optimize hadronic rejection. However, signal extraction can be confirmed if background fluctuation between ON and OFF-axis source is not dominant, so an important step in the validation of the analysis method is to observe and analyse data by comparing two sets of OFF-source regions (called dark regions), located at a similar declination as of Crab nebula ($\simeq 22°$). A statistical significance less than 3 σ was obtained from 6.6 hours of dark region data (13 pairs) in our preliminary analysis, which indicates that systematic effects due to sky and time differences during observations are not dominant in our data/analysis. The analysis of 9.1 hour of Crab nebula data (13 pairs) from the period Sept-Dec 2008 gives about 6.0 σ, corresponding to 4.1 ± 0.7 $counts\ min^{-1}$ above ~ 250 GeV (Britto et al. 2009a,b).

In our earlier analysis, T_0's were computed by using all triggering events, *i.e.* events with $NTT \geq 4$. However, the more telescopes we used in reconstructing the Cherenkov wavefront, the more accurate should be the space angle estimation, as the impact parameter of the shower will be smaller. In the same way, estimation of T_0's is expected to be more accurate when we keep only events with NTT=7 to compute TDC differences, as the curvature of the Cherenkow wavefront is smaller (the impact parameter is smaller, so the plane front approximation of the spherical front whose impact parameter is unknown will be more accurate). We show in Fig. 1 the count rates of dark regions using T_0's computed with all events versus T_0's computed using only 7 fold events. We notice less fluctuation in the count rates while using the new set of T_0's: the standard deviation is equal to 3.8 in the latter case, but 6.7 in the former one.

4 Development of a new analysis for HAGAR

Recent developments in our analysis as well as the upgrade of our hardware setup provide us with additional tools to improve our signal extraction methods.

4.1 Improvement of the timing analysis using T_0's

The T_0 value of Telescope 7 (central telescope) is set at 0 as the reference (Fig. 2 *(bottom left)*). The difference between two extremes T_0 values can be as large as 20 ns. As we require a timing precision of 1 ns, the accuracy of the calculation of T_0's is fundamental. In the process of establishing an accurate analysis method, we have

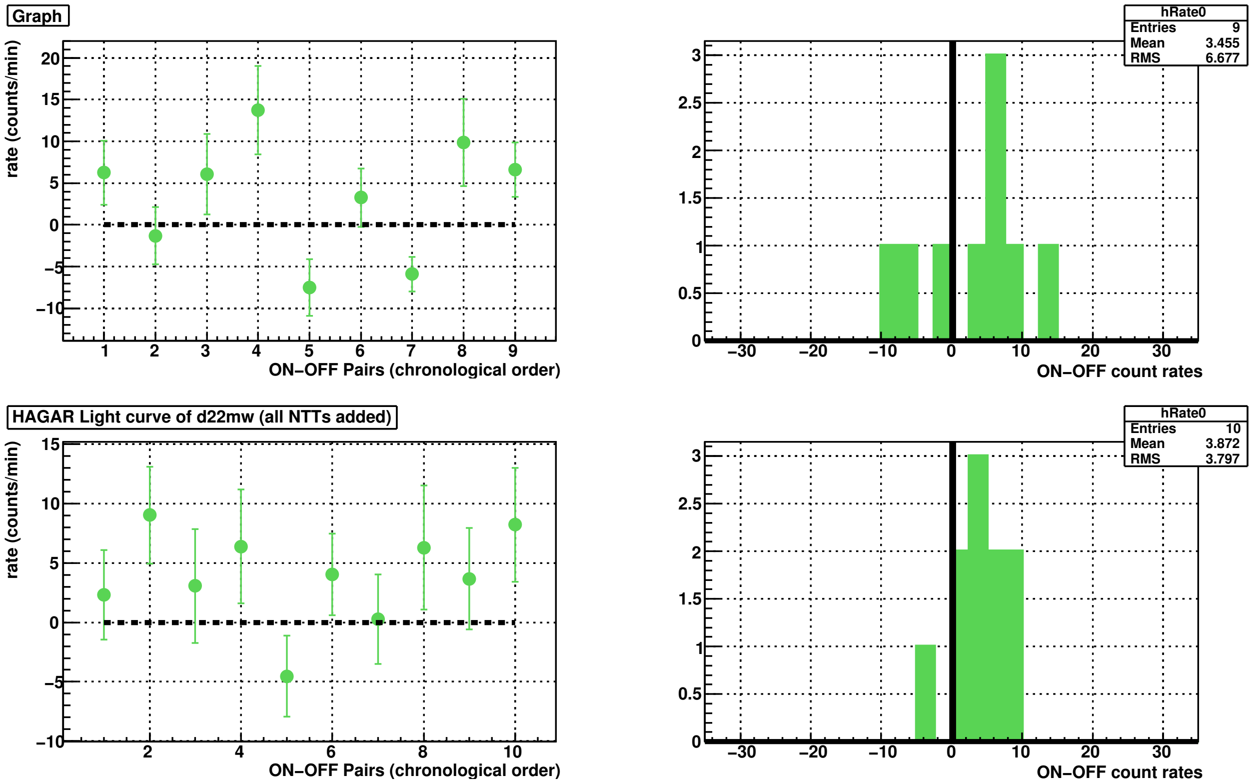

Fig. 1. Count rates from dark regions and distribution of these count rates. *Top:* Analysis with T_0's computed using all events. *Bottom:* Analysis with T_0's computed using events with NTT=7 only.

investigated several ways of computing T_0's. As a dedicated calibration system which would flash same amount of light simultaneously at each PMT is not yet implemented, we compute T_0's using real cosmic-ray events from fix angle runs, as already mentionned above. We need to perform fix angle runs for a long enough duration (typically 40 to 60 mins), so that our statistics is relevant to fit the mean values of the TDC differences.

We have recently found out that the result of the computation of a set of T_0's is dependant of the geometry of the telescope location in the array. As we require that at least 4 telescopes out of 7 get a signal above a preset threshold, we have 64 possible combinations: events which trigger Tel. 1,2,3,4, events which trigger Tel. 1,2,3,5, etc, until events which trigger the combination 1,2,3,4,5,6,7. Through every 64 trigger combination, HAGAR samples the Cherenkov front with a bias which is inherent to the geometric combination of telescopes. The 7-Fold configuration will sample a larger part of the Cherenkov wavefront (which corresponds in average to a smaller impact parameter of the shower, as described above), the combination 1,2,6,7 will sample a smaller part, the combination 1,5,6,7 will sample another smaller part of the wavefront (Fig. 2 *(bottom left)*). Preliminary tests showed us relevance of analysing source data using the 64 combinations of T_0's. We show in Fig. 2 the comparison of space angle distributions displayed for each NTT, when computed by two different methods. The *bottom left* figure contains the space angle distributions computed by applying only one value of T_0 per telescope (computed with 7 fold events only). The *bottom right* figure is after application of the 64 T_0 sets of values (one set per trigger combination). A sharper shape, as well as a smaller mean value of the space angle of NTT=4, 5 and 6, is observed. We expect this new method to allow a more accurate hadronic rejection through the space angle analysis cut.

4.2 Flash ADCs

Since April 2009, we collect data using a parallel acquisition system of Flash ADC in addition to the regular CAMAC-based data acquisition system (TDCs and QDCs). We use two 4-channel modules of Acqiris flash ADC (FADC) digitizer model DC271A. This is a 8 bit compact PCI digitizer with 1 GHz bandwidth with 50 Ω resistance and sampling rate of 1 GS/s. Seven telescope pulses are input to this module. This will enable

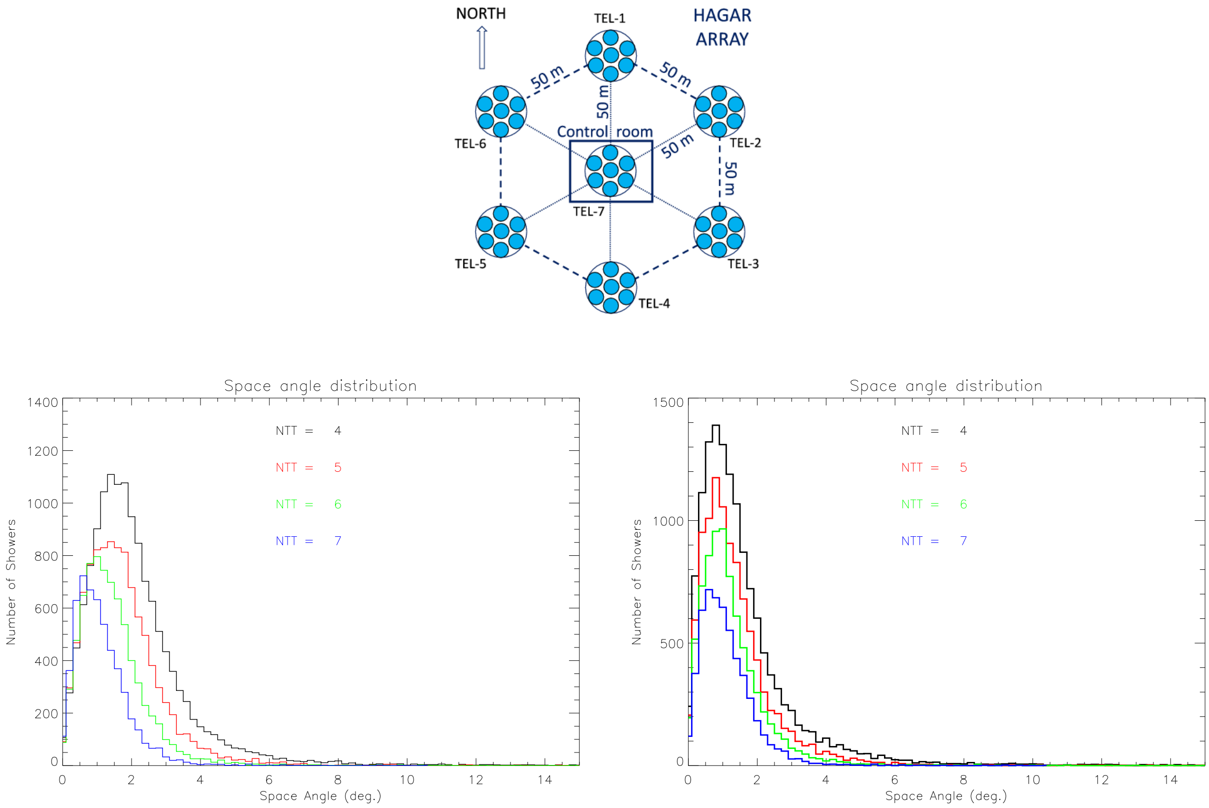

Fig. 2. *Top:* HAGAR layout of the 7 telescopes. *Bottom left and right:* Space angles for the four NTTs of a fix angle run. *Bottom left:* a single value of T_0 per telescope; *Bottom right:* 64 sets of T_0's.

us to study pulse shape, use gamma-hadron separation parameters based on pulse shape, reduce night sky background contribution by restricting window around Cherenkov pulse and also incorporate a technique for a software padding, as applied for the CELESTE experiment (Naurois et al. 2002). We show in Fig. 3 *(left)* a typical saturated FADC event, with a typical pulse fit by a log-normal function (enclosed). We see, on the *right* figure, a zoom on the first 40 nanoseconds, whose counts correspond to a typical night sky background light on FADCs. These 40 ns are used to plot the pedestal of the night sky background for each telescope channel. By comparing NSB in the ON versus OFF data acquisition, we can evaluate the NSB difference and we can expect to balance this difference by an offline addition of noise on the channel with less noise, through the procedure of software padding.

4.3 Hardware upgrade

In July 2010 several upgrades have been implemented in our hardware setup: a meter for monitoring the night sky brightness, and a home made programmable discriminator unit where threshold level could be remotely controled. Also, the trigger circuit was modified and upgraded in order to reduce the width of the coincidence window (to reduce chance triggers). Further upgradation is also planned to linearly add all telescope pulses through what we call "Grand Sum pulse", which could reduce the HAGAR energy threshold. This *Grand Sum* logic will demand the installation of programmable analog delays. Lastly, a new data format for additional house keeping information has been implemented.

5 Conclusion

Observation with the HAGAR telescope array are regular since September 2008. Several Galactic and extra-galactic sources are observed. After reporting preliminary results on the Crab nebula and dark regions, we have implemented new developments in our analysis method. Improvement of the method and development of new

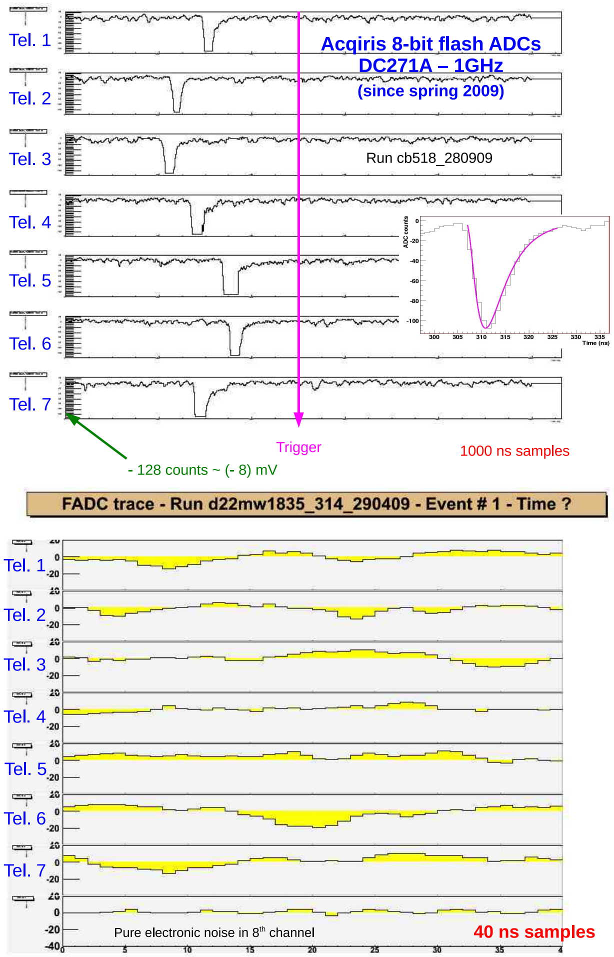

Fig. 3. *Left:* One FADC event, saturated for the seven telescope pulses. Enclosed is a typical event fit with a gamma function. *Right:* Zoom on the 40 first nanoseconds of the FADC windows, for each royal sum, for a typical event (only night sky and electronic noise. The 8^{th} channel is not connected to any telescope.

analysis softwares are still under going. Upgrade of the hardware also give us good expectation in controlling more systematics and decreasing the energy threshold.

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References

Acharya, B. S. et al, 2009, Paper # icrc0669, Proc. of the 31^{st} ICRC

Britto, R. J. et al, 2009a, Proc. of SF2A-2009, Annual meeting of the French Society of Astronomy and Astrophysics, M. Heydari-Malayeri, C. Reylé and R. Samadi (eds), p. 131

Britto, R. J. et al, 2009b, Paper # icrc0669, Proc. of the 31^{st} ICRC

Britto, R. J. et al, 2010, this volume, p. 135 (`http://proc.sf2a.asso.fr/2010/2010sf2a.conf..0135B.pdf`)

Chitnis, V. R. et al, 2009a, Paper # icrc0696, Proc. of the 31^{st} ICRC

Chitnis, V. R. et al, 2009b, Paper # icrc0697, Proc. of the 31^{st} ICRC

De Naurois, M. et al. 2002, ApJ, 566, 343

Yadav, K. K. et al, 2009, Proc. of the 44^{th} *Rencontres de Moriond*, `arXiv.org/abs/0904.3647`