



Gamma-Ray, Neutrino & Gravitational Wave Detection

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Abstract. This report is based on a rapporteur talk presented at the 30th International Cosmic Ray Conference held in Merida, Mexico (July 2007), and covers three of the OG sessions devoted to neutrino, gravitational wave, and γ -ray detection.

Introduction & Overview

Summarised here are key results from papers and posters presented in the sessions OG 2.5 (neutrino detection), 2.6 (gravitational wave detection), and 2.7 (γ -ray detection). The number of presentations in each session was 75 (OG 2.7), 19 (OG 2.5) and 2 (OG 2.6), with γ -ray detection clearly dominating. OG 2.5 was devoted to neutrino/ γ -ray connections and related experimental and theoretical issues and contains overlaps with the HE 2 session. A more detailed summary of neutrino detectors and related astrophysical theory can be found in the HE 2 rapporteur by Tom Gaisser [1]. Here, summaries of each session are ordered according to the number of contributions. I have kept to citing only ICRC presentations/posters since in most cases a detailed list of references may be found therein.

Gamma-Ray Detection

This γ -ray detection session encompassed technical status reports from space and ground γ -ray instruments, summaries of their analysis techniques and performance, and plans for future instruments. Results from γ -ray instruments (sessions OG 2.1 to 2.4) are summarised by Jim Hinton [2] and I will only touch on a few key relevant results.

Ground-Based γ -Ray Detectors: Current & Funded

Ground-based γ -ray detectors can be broadly split into three camps: (i) Telescopes employing

the Imaging Atmospheric Cherenkov Technique (IACT) including those with ≥ 2 telescopes operating as stereoscopic arrays, (ii) Water Cherenkov detectors, and (iii) Ground arrays.

IACT Detectors/Arrays

There are four major IACT detectors/arrays in operation today, and status reports presented at this conference on the two most recently commissioned systems — VERITAS and MAGIC/MAGIC-II, were dominant in number. Both H.E.S.S. and CANGAROO-III have been in full operation since ~ 2004 and much of their technical details have been presented at previous ICRCs, although an updated status of CANGAROO-III was presented here.

After many (non-scientific) delays, VERITAS [3] achieved first light with four telescopes in April 2007. [4] presented an overview of the VERITAS array which comprises $4 \times 106\text{m}^2$ telescopes situated at the Basecamp at Fred Lawrence Whipple Observatory, Mt. Hopkins, Arizona (Fig 1). The optics of each telescope comprises a Davies-Cotton dish with 345 mirror segments [5]. Mirror mis-alignment due to dish deformation vs. elevation has been successfully corrected using a laser alignment system [6]. The telescopes' cameras comprise a 499 photomultiplier (Phillips XP 2970/02 PMT) pixel array [7], providing a $\sim 3.5^\circ$ field of view (FoV). The size (diameter) of each pixel is 0.15° . The trigger system is based on three levels: L1 - pixel; L2 - camera pixel pattern; L3 - array trigger [8]. A pixel

trigger of 4–5 pe. (photoelectrons) is first applied. The camera is triggered when (presently) 3 adjacent pixels within a pre-defined group are triggered within 6 ns (see [9] for details). This pattern logic greatly reduces accidental triggers due to skynoise. The inter-telescope array trigger (L3) is met whenever ≥ 2 telescopes trigger within a time window up to 125 ns, depending on the zenith and azimuth angle of observations. The 3-telescope array trigger rate is ~ 220 Hz with a 10% dead time. PMT pulses are digitised using 500 MHz (VME-based) flash ADCs (FADCs) [10]. Several methods based on FADC sampling and filtering to extract the Cherenkov pulse arrival time were evaluated by [11], with a combination of resampling and linear interpolation yielding a ~ 0.2 ns time resolution. Calibration issues encompassing the use of single-pe runs, muon ring data and flat fielding were summarised by [12]. [13] also discussed the use of laser shots as a way to correct for local atmospheric effects. A data analysis chain outlined by [14] focused on the specific event display and VEGAS [15] packages. Together they handle the image formation (from FADCs), image calibration, cleaning (employing a well-known picture/boundary philosophy) and stereo reconstruction of event direction. As for any new instrument such as this, observations of the Crab provide the first real test and results have clearly met expectations gleaned from earlier Monte-Carlo (MC) studies [16] (see Fig. 1). Overall the VERITAS array provides an eventwise angular resolution better than 0.14° and a 5σ detection of a 10% Crab flux in under 1 hour. With all of these results, it's now clear that VERITAS is fully functioning and we eagerly await the new high energy astrophysics to come (see [2] for a summary of first VERITAS results).

The MAGIC telescope [17] has been in full operation since 2004 and results have flowed steadily since. Technical issues presented at this conference were devoted to updates of the MAGIC camera & electronics, improvements to data analysis, and the status of phase II (MAGIC-II) of the project in which a second telescope will soon be operational. An overview of MAGIC/MAGIC-II was presented by [18]. MAGIC is a single large (236 m^2) telescope situated at the 2200 m a.s.l on the Canary Island of La Palma. The MAGIC

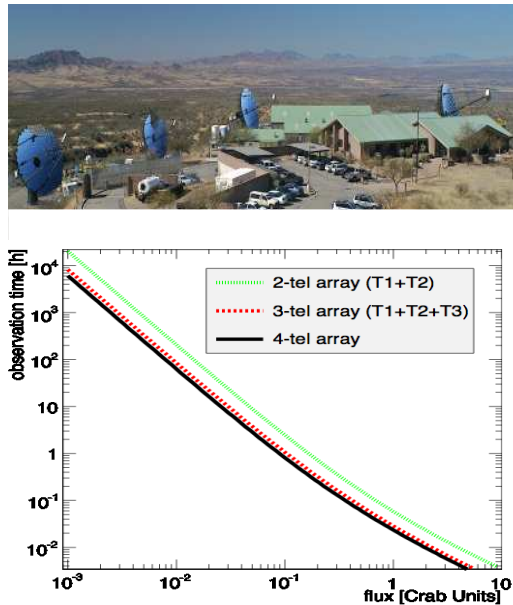


Fig. 1. Top: View of the VERITAS 4-telescope IACT array [4]; Bottom: VERITAS flux sensitivity (Crab units) of the VERITAS array for several telescope (T1, T2, etc..) combinations [16].

team have emphasised the use of new technology such as lightweight construction (for fast slewing, ~ 40 s, motivated by GRB followups), optical fibre data transmission, and research into high quantum efficiency PMTs and other photon detectors. The latter is motivated by the push to reduce the energy threshold of ground-based γ -ray instruments to well below 100 GeV. Presently the trigger threshold is of MAGIC ~ 50 GeV and the 5σ flux sensitivity for 50 h observation is $\sim 2\%$ Crab for energies above 100 GeV. Effort has gone into development of hadronic background rejection and one method summarised by [19] based on utilising the Cherenkov light present in hadronic components of cosmic-ray (CR) showers, which leads to an increased number of pixels with small (1–1.5 pe.) signals compared to γ -ray images, indicated improved hadron rejection by a factor ~ 2.6 (Crab excess significance ~ 9 to 12σ) for energies $E < 200$ GeV. The lightweight nature of the MAGIC dish has meant that active mirror control is necessary and [20] described the successful method of mirror re-alignment. Using a pre-determined database of mirror positions vs. az-

imuth and altitude (derived from laser and star measurements), the re-alignment procedure can be completed in ~ 10 s, in parallel with telescope slewing such that the re-alignment adds no additional time delay. Extending the duty cycle of ground-based γ -ray instruments has also been a focus with observations running into bright Moon phases and even into twilight have been investigated [21]. With this in mind the MAGIC camera PMTs are operated at lower gains, $\text{few} \times 10^4$ as opposed to the $\sim 10^6$ values traditionally used. In order to control accidental triggers the pixel discriminator threshold (DT) was increased with Moon brightness, with a resultant increase in energy threshold (Fig. 2). The corresponding reduction in event statistics extends up to image *size* $\sim 10^4$, however no strong changes in distributions of image *length* and *width* for *size* ≥ 400 pe. was noticed suggesting that the hadron rejection cuts can remain essentially unchanged at these higher thresholds. Improvements (Feb. 2007) to the MAGIC electronics with multiplexed 2 GHz FADCs (replacing the previous 300 MHz system) have also indicated improved hadron rejection based on timing differences between γ -ray and hadron showers [22, 23]. MAGIC-II will see an additional telescope constructed 85 m away from the first MAGIC telescope. The new dish and mount are in place (Fig. 2) and first light is expected in the first half of 2008. Several improvements are foreseen in the second telescope. FADC type electronics based on low power switched capacitor ring buffers (Domino Ring Buffer - not unlike the Analogue Ring Samplers in use by H.E.S.S.) are planned, and have been successfully tested on site. The camera, comprising $1039 \times 0.1^\circ$ pixels will subtend a FoV 3.5° , similar to the MAGIC-I camera, but have a larger trigger area [24]. After initially equipping the camera with $\text{QE} \sim 30\%$ PMTs, higher QE ($\sim 50\%$) PMTs are planned [25]. Mirror segments about 4 times larger in area (1 m^2 area) compared to MAGIC-I are also installed [26]. Overall, with the advantage of stereoscopy, the MAGIC-II system is expected to operate with sensitivity a factor ~ 3 better and energy threshold $\sim 40\%$ lower than the single telescope (Fig. 2). Looking further afield, research into avalanche photodiodes (APDs) continues and [27] summarised field trials of prototype Hamamatsu APD arrays operated in Geiger mode. APDs can achieve QE of 60%

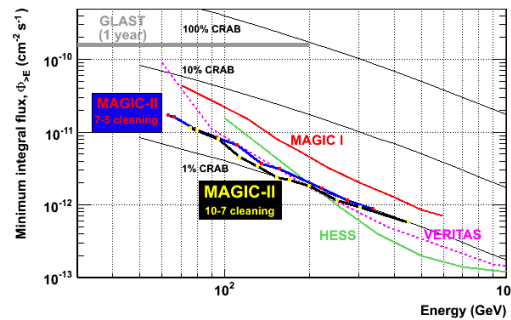
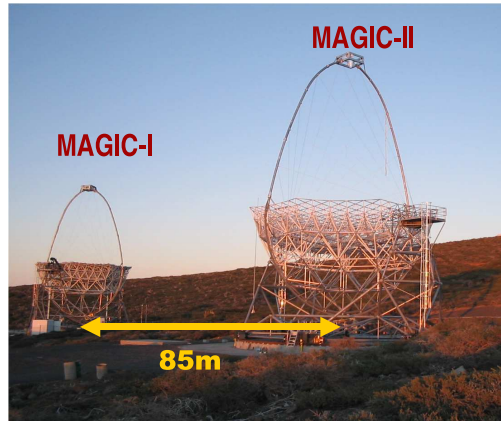
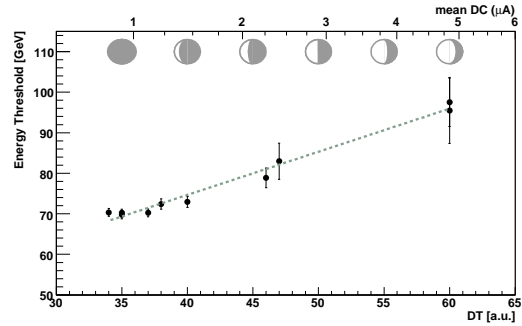


Fig. 2. Top: Variation of MAGIC energy threshold vs. pixel discriminator threshold (DT) and Moon phase [21]. Middle: Picture of the two MAGIC telescopes – MAGIC-II [18]. Bottom: MAGIC-II flux sensitivity (for two versions of image cleaning) compared with that from other γ -ray telescopes [18].

or more and present a way to considerably reduce the energy threshold of γ -ray telescopes, despite the drawbacks of small (mm) size, high cross talk and dark current. After initial tests on a solar concentrator, they were installed on the MAGIC camera for several nights. Cherenkov signals from the installed APDs were obtained and a signal ratio (compared to adjacent conventional PMTs of the MAGIC camera) of about 1.6 was indicated, consistent with the improvement in QE. Additionally, single and multiple pe. peaks were resolved using low output laser runs.

The status of the 4-telescope CANGAROO-III system [28] was summarised by [29] with a focus on astronomical results. Presently only three of the four telescopes operate with the same camera type and are used in stereo operations. Data analysis is based on the Fisher discriminant derived from a linear combination of image parameters such as *width* and *length*. Funding for upgrades to the telescope mirrors (to improve the overall angular resolution) and T1 electronics (to bring T1 into the stereo trigger) have been sought.

The GAW (Gamma AirWatch) project summarised by [30, 31] is the first serious attempt to operate an IACT system with refractive optics, in this case a Fresnel lens. A key point is that the Fresnel lens permits a very wide FoV up to 24° in diameter to be employed for wide field surveys. The GAW telescopes consist of tiled multi-anode PMTs (MAPMT) on alt/az mounts coupled to the Fresnel (2.13 m diameter f/1.2) optic system. The Fresnel lens (Fig. 3) is of a tessellated design from Fresnel Technologies Inc. (Ft. Worth, Texas). The Hamamatsu R7600-03-M64 (64 pixel) MAPMTs have pixel sizes of ~ 4 arcmin. Phase-I (under construction at Calar Alto 2150 m a.s.l.) will see three identical telescopes arranged in a triangle of side 80 m (Fig. 3), each equipped with $5^\circ \times 5^\circ$ FoV cameras. Phase-II will see the cameras expanded to cover $24^\circ \times 24^\circ$. The small pixel sizes mean that they are essentially photon limited and thus can operate without expensive ADCs/FADCs. Simulations so far suggest an energy threshold of about 0.5 TeV and angular resolution 0.3° to 0.1° , improving with energy. The expected point source flux sensitivity of GAW (Phase II) is also presented in Fig. 3 and appears to match that of the HEGRA IACT-System.

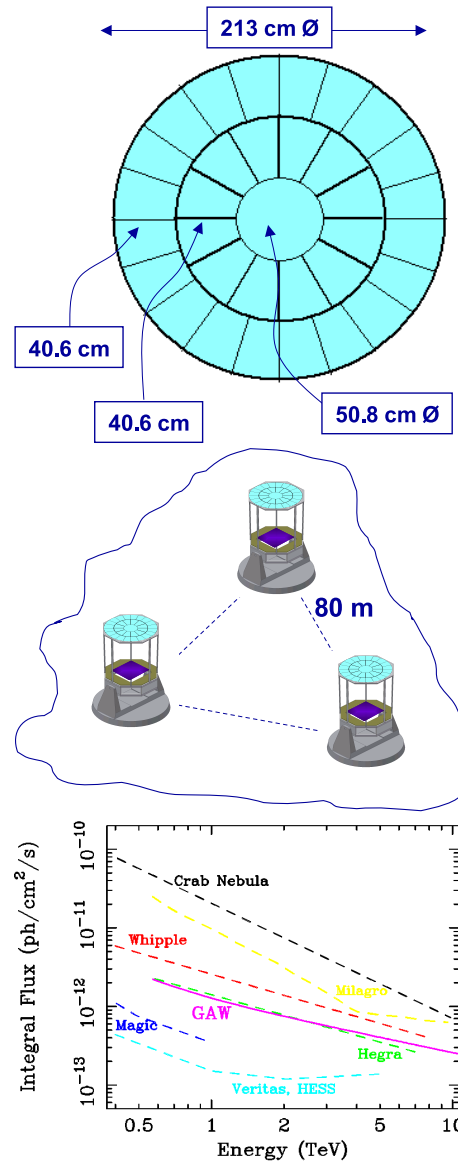


Fig. 3. Top: Fresnel lens design for GAW. Middle: Layout of the GAW 3-telescope array Bottom: GAW phase-II flux sensitivity (5σ in 50 h). Plots are taken from [30].

Another project with large FoV is ASHRA (All-sky Survey High Resolution Air-shower detector), summarised by [32]. ASHRA has a multi-function focus, aiming to cover the fields of optical/UV photometry, TeV γ -ray and multi-TeV neutrino detection, and EeV CR detection. The ASHRA telescopes, under construction on Mauna Loa, Hawaii (3300 m a.s.l.) since 2006, employ

ultra wide field modified Baker-Nunn optics which provide arcmin focusing over a $\sim 40^\circ$ FoV (see Fig. 4 for a photograph). Detected light is amplified by a 20 inch image intensifier and then diverted to a gated CMOS sensor with 2048×2048 pixels of size 1.2 arcmin (Fig. 4). Triggers and gates of different time resolution are used for optical, Cherenkov (TeV γ -ray and multi-TeV neutrino) and fluorescence (EeV CRs) detection. An example Cherenkov image is presented in Fig. 4. Several ASHRA telescopes will be operated in a local group to provide a full survey of the sky, and eventually, several groups are envisaged separated by about 30 km on Mauna Loa, Mauna Kea, and Hualali. Its expected integral flux sensitivity (5σ in 500 h) is $\sim 10^{-12}$ and $\sim 10^{-14}$ $\text{ph cm}^{-2} \text{s}^{-1}$ for energies $E > 1$ and 100 TeV respectively. Arcmin angular resolution is also expected in the fluorescence detection mode.

Water Cherenkov/Ground Arrays

There was no contribution at this conference devoted specifically to the technical aspects of the MILAGRO water Cherenkov detector. However, it is worth highlighting here the fact that with its discovery of degree-scale multi-TeV γ -ray emission from the Cygnus and other northern Galactic Plane regions (see [33, 34, 35]), MILAGRO has clearly demonstrated the viability of densely sampling the extensive air shower (EAS) particles, in this case, via their Cherenkov emission in water. This has provided a solid launching pad for the HAWC proposal, and impetus for upgrades of the Tibet AS ground array outlined later in this summary.

A new ground array recently commissioned (mid 2006) at Yangbajing, Tibet (4300 m a.s.l) is the ARGO-YBJ experiment, summarised by [36]. ARGO-YBJ consists of a dense array (>10000) of resistive plate chambers (RPCs) covering an area $\sim 100 \times 100$ m. The RPCs provide a signal proportional to the number of incoming charged EAS particles. Based on timing properties of the triggered RPCs reconstruction of EAS can be performed. A point source angular resolution of $\sim 0.5^\circ$ is indicated based on Moon-shadow observations. To date a 5σ excess has been seen from the Crab in 290 hr after employing a cut based on the density of triggered detectors (so-called Pads).

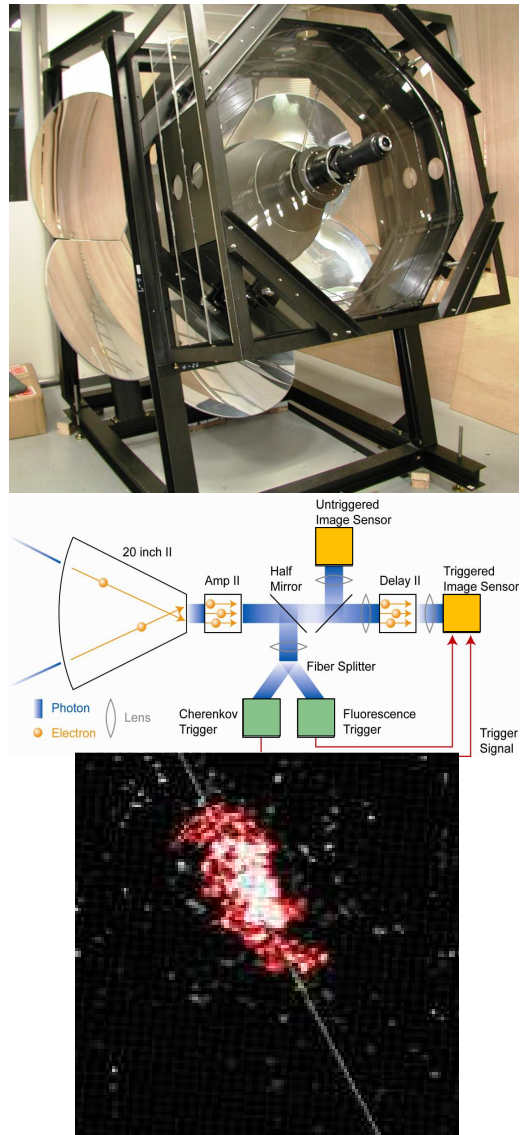


Fig. 4. Top: Modified Baker-Nunn optic of an ASHRA telescope. Middle: Detector and data flow for the various types of signal (optical, Cherenkov, fluorescence). Bottom: Example Cherenkov image. All images from [32].

Spaced-Based γ -Ray Detectors: Current & Funded

In this category we find the eagerly awaited GLAST mission, which will yield a wealth of new astrophysics in the ~ 20 MeV to 10's of GeV range, and effectively close the energy gap between space and ground-based instruments. An

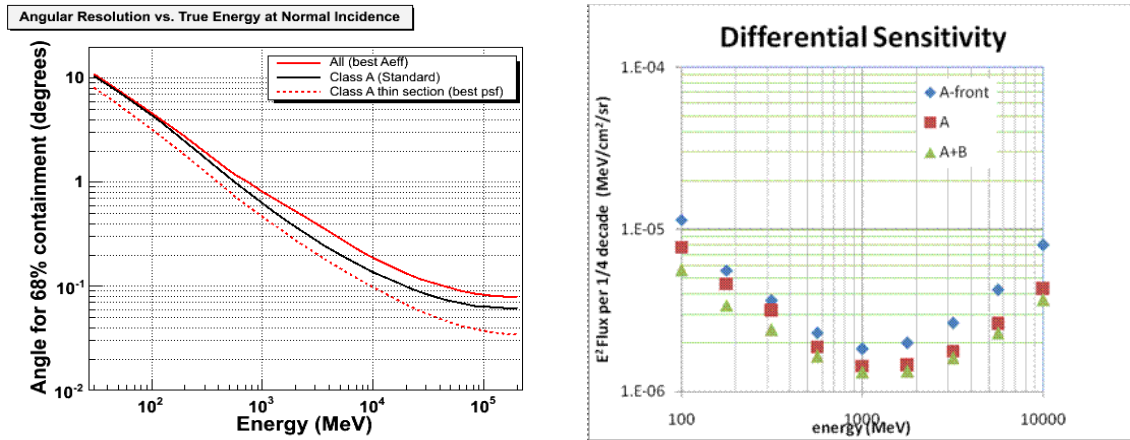


Fig. 5. Left: GLAST LAT angular resolution vs. energy. Right GLAST LAT flux sensitivity for one year observation. Figures are from [37].

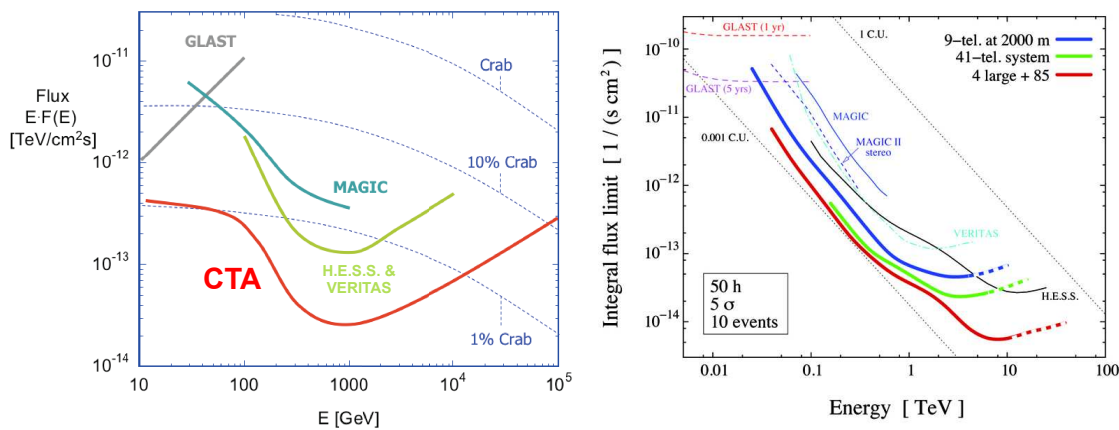


Fig. 6. Left: Desired flux sensitivity of CTA. Right Integral flux sensitivities for several telescope combinations considered in CTA simulations so far – 9-tel (group 1), 41-tel (group 2), 85+4-tel (group 3). See text for explanations of telescope groups. Figures are from [41, 44].

overview of GLAST, its timeline, and organisational aspects of data handling were presented by [37]. GLAST comprises two instruments, the LAT (Large Area Telescope: see [38] for details) covering the 20 MeV to >100 GeV range with a 2.2 sr FoV, and the GBM (GLAST Burst Monitor) operating in the 8 keV to 20 MeV range with a 9.5 sr FoV. The GBM will trigger on ~ 215 GRBs per year, with ~ 70 of these within the LAT FoV. The LAT comprises a 4×4 array of dense Si-strip trackers (converting incoming γ -rays to pairs), surrounded by an anti-coincidence shield for the rejection of CR particles. At the base of each Si tracker is a CsI calorimeter for γ -ray energy estimation and also to aid in CR rejection. The angular resolution of LAT improves strongly with energy to $\leq 0.2^\circ$ for energies above 10 GeV, and its flux sensitivity is a factor 50 or more better than that of EGRET (Fig. 5). As a result of LAT sky surveys the number of GeV sources is expected to increase by a factor 10 with sub-arcmin localisation of bright sources. At the time of the conference both instruments had completed their final lab and environment testing and had been integrated with the spacecraft. Transport to the launch site and integration with the Delta II rocket launch vehicle is expected in the latter half of this year. The anticipated launch is in early 2008. After a ~ 60 day checkout immediately after launch, the first year sky survey will commence. Within this timeframe, re-positioning to cover bright bursts will be carried out, and LAT raw data will remain proprietary to the GLAST collaboration. However all GBM data and high level information (flux, spectra, location) for LAT bursts and selected sources monitored by LAT will be made public (this monitoring list is available at http://glast.gsfc.nasa.gov/ssc/data/policy/LAT_Monitored_Sources.html). After this first year, GLAST observations will be driven by peer-reviewed proposals from guest investigators (GI) with a default state being a sky survey mode. GLAST Multiwavelength coordination policy was outlined by [39] and details of the GLAST GI programme can be found at <http://glast.gsfc.nasa.gov/ssc/proposals/>. The first phase deadline has already passed at the time of writing however further GI phases will be announced. In addition to this, strong links with

IACT arrays are under development in order to maximise the astrophysics from transient γ -ray sources.

Ground-Based γ -Ray Detectors: New Ideas & Proposals

The success of H.E.S.S. in increasing the number of TeV γ -ray sources (eg. see the interactive web-based TeV catalogue *TeVCaT* summarised by [40] at <http://tevcat.uchicago.edu>) has prompted many in the fields of particle astrophysics and high energy astrophysics to seriously consider the next step in ground-based γ -ray astronomy. A major component of the OG.2.7 sessions were devoted to future γ -ray IACT arrays.

Summarised by [41], the European-led Cherenkov Telescope Array (CTA) project [42] is looking at the development of new γ -ray IACT arrays, aiming to realise a factor 10 or more improvement in flux sensitivity (to the 1 mCrab level - see Fig 6) in the 10's of GeV to ~ 100 TeV energy range with angular resolution down to the arcmin level in specific energy ranges. CTA represents a large step beyond H.E.S.S. and MAGIC-II, and over 30 institutes have expressed interest so far. The science case for CTA was outlined by [43]. Specific working groups devoted to science drivers and technical aspects have been setup. The philosophy is to make use of existing and proven technologies/methods, such as conventional PMTs (peak QE $\sim 25\%$) and electronics, and to have the telescopes operate as an open public observatory available to the scientific community. Northern and southern sites are presently foreseen with a Galactic source emphasis in the south, and extragalactic emphasis in the north, although there will naturally be considerable overlap. MC studies are underway [44], and are considering various arrangements of telescopes (at ~ 2000 m a.s.l.) and telescope size combinations, concentrating first on the low (10 GeV) to medium (1 TeV) range. Preliminary flux sensitivity results for telescope groups (1) 9×420 m², (2) 41×100 m² and (3) 85×100 m² + 4×600 m² were reported (Fig. 6). Group (3), with the largest number of telescopes, spread over a 1 km \times 1 km area is a factor ~ 10 more sensitive than H.E.S.S. Further work is ongoing to optimise CR background rejection and stereo reconstruction, and performance im-

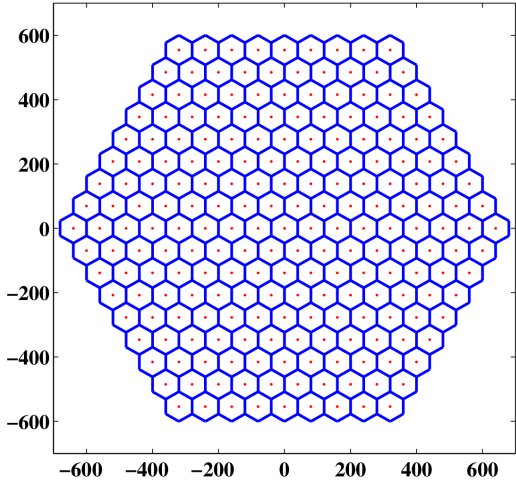


Fig. 7. Array layout for 217×10 m diameter telescopes with 80 m spacing [47].

provements beyond these results are anticipated. Cost estimates for CTA so far place the southern facility at ~ 100 MEuro, and the northern facility at ~ 50 MEuro. Emphasising its importance to future European science, CTA was shortlisted in the ESFRI (European Strategy Forum on Research Infrastructures) 2006 reports, and a design study proposal was submitted to the European FP7 funding round.

The US-based White Paper [45, 46] sets out to map the path to a future ground-based γ -ray instrument. It is the result of several meetings in the US devoted to the future of ground-based γ -ray astronomy in that country (Malibu 2005, Santa Fe 2006, Chicago 2007). Initiatives resulting from these have been the White Paper itself (due in late 2007) and R&D proposals for new telescopes. Arising from this the AGIS concept (Advanced Gamma-Ray Imaging System) has gained momentum. Several working groups are focused on specific aspects of the Paper such as different source types and technical aspects. The White Paper is overseen by an editorial board, comprising eight prominent members of the community. The next meeting *Towards the Future of Very High Energy Gamma-Ray Astronomy* (<http://www-conf.slac.stanford.edu/vhegra/>) taking place at SLAC in November 2007, will further advance plans for AGIS and White Paper content.

Working towards AGIS, [47] outlined results from MC simulations of a dense telescope array covering a 1 km^2 on the ground. 217×10 m diameter telescopes were arranged on a hexagonal grid with 80 m spacing (Fig. 7). This small telescope spacing ensures that each event is well-sampled – on average three telescopes see the same event, maintaining high performance (in terms of angular resolution and CR background rejection) across its desired energy range of < 50 GeV to ~ 1 TeV. Their simulations also showed that optimal sensitivity was obtained using camera pixel sizes of 2 to 4 arcmin, for the energies 40 and 100 GeV tested. This small pixel size prompted investigation into new type of mirror optics beyond the conventional prime-focus types currently in use. Optics based on the Schwarzschild-Couder (SC) design employing a secondary reflecting surface and curved focal plane have been studied in detail [48]. The segmented primary and secondary mirror are aspheric and are formed to correct for spherical and coma aberrations. Ray tracing was used to find mirror parameters that minimised astigmatism and effective area losses vs. off-axis angle. Fig. 8 depicts an off-axis ray tracing situation, mirror segmented patterns, and the arcmin focusing performance out to 7° off-axis. An additional consequence is that the focal plane scale is much reduced (by a factor > 2) compared to a prime-focus system, bringing into play multi anode PMTs with small pixel pitches (and considerably less per pixel cost compared to single PMTs).

An additional optics design based on Schmidt optics with a Fresnel corrector was summarised by [49]. Practical aspects of construction of the Fresnel lens, and primary mirror tessellation were also discussed. Focusing of ~ 1 arcmin was demonstrated in their $f/0.8$ system out to off-axis angles of $\sim 7.5^\circ$. This, and the SC design discussed earlier, offer promising ways to realise ultra-wide FoV IACTs for the next step in γ -ray astronomy.

Continuing with the future IACT design, [50] has looked at the design of a three telescope array with an emphasis on sub-100 GeV energies. Telescope diameters of 17 to 28 m (with 3° FoV camera with 0.07° pixel sizes) with separation 50 to 100 m were considered giving peak detection γ -ray rates at 50 and 25 GeV respectively (for 50 and 80 m separation). CR background rejection based

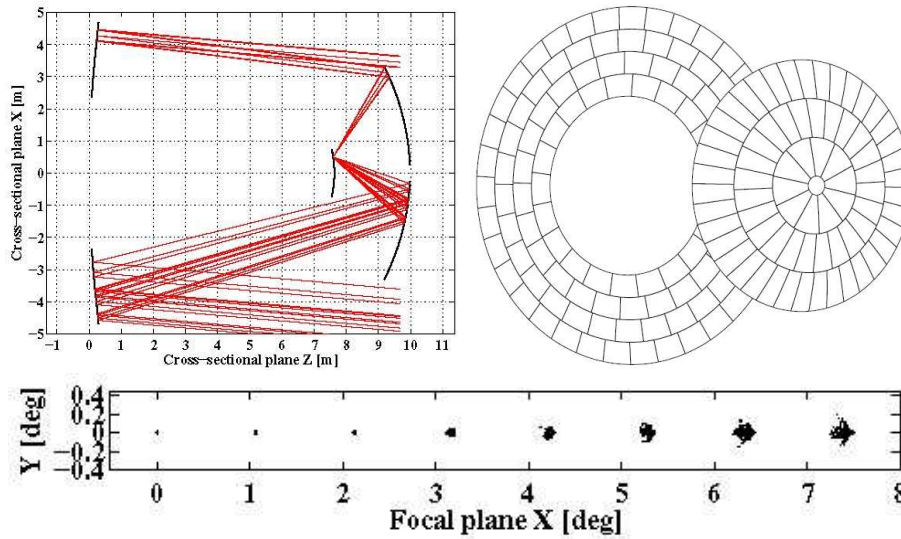


Fig. 8. Upper left: Off axis ray tracing for the Schwarzschild-Couder (SC) outlined by [47, 48]. Upper right: Segmented primary and secondary mirror layouts. Bottom: Off-axis focusing of a particular SC design.

on scaled width and length, as well as angular resolution were studied for the various telescope sizes. Angular resolution was found to improve with telescope size, varying primarily in the $E < 50$ TeV regime (Fig. 9 presents results for a 50 m separation).

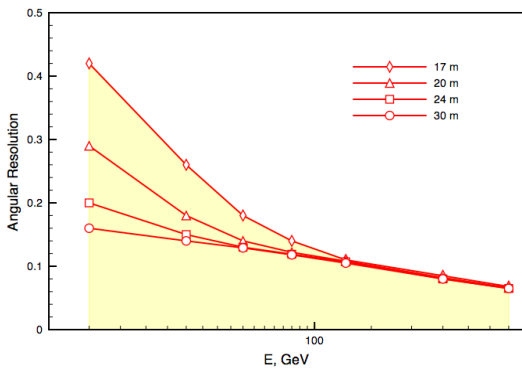


Fig. 9. Angular resolution for a three telescope system vs. telescope diameter [50] (telescope separation is 50 m).

Idealised detectors (perfect optics and cameras) were considered by [51] in their optimisation study of a 3×18 m diameter telescope array at a moderately high altitude (2700 m a.s.l.) — based on a possible site of a northern IACT array. Simi-

lar to the previously described study, the focus was on low energy γ -rays (here 3 to 2000 GeV). They found that a large camera FoVs of $\sim 8^\circ$ provide improved point-source sensitivity and pixel sizes up to $\sim 0.15^\circ$ provide similar performance as with a perfect camera. Further work is in progress to extend the number of telescopes.

Studies of the stereo reconstruction of γ -ray Cherenkov images was a focus of work presented by [52] in their simulations of arrays of up to 100 telescopes. Telescopes of 12.5 m and 30 m diameter were considered at 1800 m and 3000 m a.s.l. respectively. Direction reconstruction was based on maximum likelihood method incorporating camera pixels from all telescope simultaneously. Optimal telescope spacings (for optimal angular resolution better than 0.1°) over the 10 GeV to 10 TeV regime appear in the range 100 to 200 m. The lower altitude site is beneficial for higher energy events due to the fact that shower development may not have fully completed at 3000 m towards higher energies.

Of interest is the MACE (Major Atmospheric Cherenkov Experiment) telescope is envisaged for the 4200 m a.s.l. site in Hanle [53]. At present the wavefront sampling experiment HAGAR is currently operating at this site. MACE is a single large 21 m diameter telescope of very similar design

to the MAGIC telescope. A 5° FoV camera with 0.1° and 0.2° pixels is being considered. Given the very high altitude of this site, the MACE telescope could operate with a threshold approaching 20 GeV. Funding permitting, construction could get underway by 2010, with a possible extension to stereoscopic operations a couple of years later.

With an emphasis mainly on higher energies (>10 TeV), [54, 55] outlined the *TenTen* IACT array concept. An array of modest-size telescopes (4 to 6 m diameter) coupled to large FoV cameras (up to 10° as permitted by conventional optics such as the Davies-Cotton design) with large telescope spacing (>200 m) is the basis behind *TenTen*. The name is derived from the >10 km² effective collection area required in the >10 TeV range for sufficient sensitivity to discover and study multi-TeV sources approaching the mCrab level. MC simulations of a cell of 5×23 m² telescopes with separation 300 m on a side was presented. Cameras of 8° FoV with $1024 \times 0.25^\circ$ pixels were employed. The cell philosophy is based on earlier experience with the 5-telescope HEGRA IACT-System and later H.E.S.S. The simulations suggest an effective area exceeding 1 km² for energies >30 TeV can be achieved (Fig. 10 presents the layout and effective area curve), as well as similar angular resolution and CR background rejection as obtained by HEGRA and H.E.S.S. in their respective energy regimes. The large effective area results mainly from the camera FoV, which permits γ -ray events to trigger out to core distances >600 m. The relative wide telescope spacing appears sufficient to provide stereoscopic views of multi-TeV γ -ray events. Each cell can operate independently if spaced sufficiently apart (eg. >1 km) such that the multi-cell performance can be easily extrapolated. A ten cell system would then provide the necessary 10 km² collection area, and based on its collection area improvement over H.E.S.S., could operate with a flux sensitivity roughly a factor 5-10 better in the 10 to >100 TeV range. Present simulation place the telescope at a near sea-level altitude (200 m a.s.l.) where a collection area improvement can be gained compared to higher altitude sites. Further optimisation of cell layout, trigger conditions, CR background rejection and site selection are currently underway.

Design studies for 1 to 100 TeV γ -ray detection were also outlined by [56].

The HAWC (High Altitude Water Cherenkov Telescope) is the planned water Cherenkov replacement of MILAGRO. Improving on MILAGRO's design, the key new aspects of HAWC (summarised by [57]), are its high altitude (4100 m at the Sierra Negra site in Mexico [58]) to improve access to shower particles, and optical isolation of the PMTs in deep (6 m) water so that only one PMT layer is sufficient for CR background rejection (Fig. 11). The optical isolation also reduces accidental triggers. The HAWC sensitivity is a factor ~ 15 better than MILAGRO, obtaining a 5σ detection on the Crab in one day, and a 30 mCrab survey of the northern sky in 2 yr (Fig. 12) with an angular resolution in the 0.25° to 0.4° range. Given its all sky FoV and 24 hr duty cycle, HAWC would be an ideal complement to future IACT arrays and will no doubt lead to new discoveries of large-scale TeV sources.

A key announcement at this conference was that Sierra Negra was officially confirmed as the site for HAWC.

At the same site as ARGO-YBJ, the Tibet Air Shower array has been in operation since 1990 and has undergone several upgrades. Presently the array consists of 789 plastic scintillator detectors of area 0.5^2 m each on a 7.5 m grid spacing. The total array area is 37000 m². Current methods to discriminate between γ and CR events in the detection of the Tail-In, Cygnus, and Crab sources were outlined by [59]. Motivated by the H.E.S.S. Galactic plane results, and to improve the CR background rejection beyond the current modest levels, it is planned to install a $\sim 200 \times 50$ m² water Cherenkov muon detectors around the scintillator array [60]. Monte Carlo simulations indicate that for energies above 10 TeV, a cut on the level of Cherenkov signal provides a CR survival efficiency of $< 10^{-2}$ in comparison to a γ -ray efficiency of >0.5 . The integral flux sensitivity of less than 10^{-14} ph cm⁻² s⁻¹ for $E > 100$ TeV (Fig. 13) is indicated.

Spaced-Based γ -Ray Detectors: New Ideas & Proposals

The two new space-based γ -ray detectors discussed at this conference centred on polarimetry

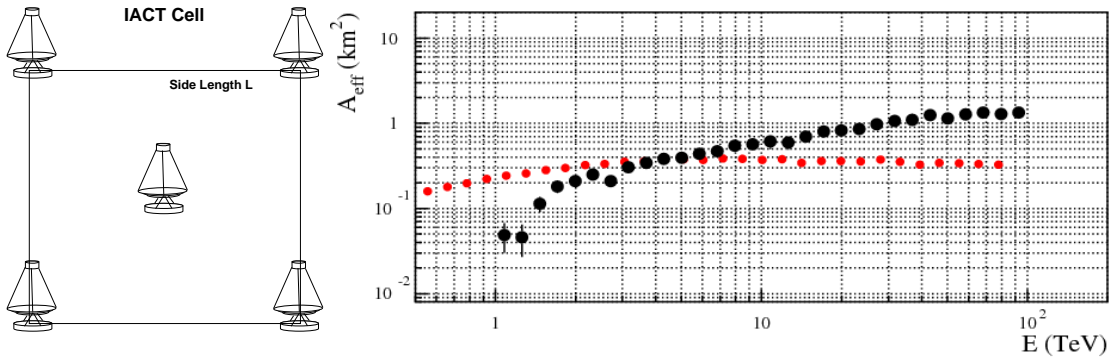


Fig. 10. Left: Layout of an IACT cell of 5 telescopes as simulated for *TenTen*. Results for $L = 300$ m were presented. Right: Effective area A_{eff} (km^2) vs energy E (TeV) for the 5-telescope cell of side length $L=300$ m, at 200 m a.s.l. (large black solid circles). The effective area achieved by H.E.S.S. is shown as small red solid circles. In both cases, no selection cuts on γ -ray events are applied.

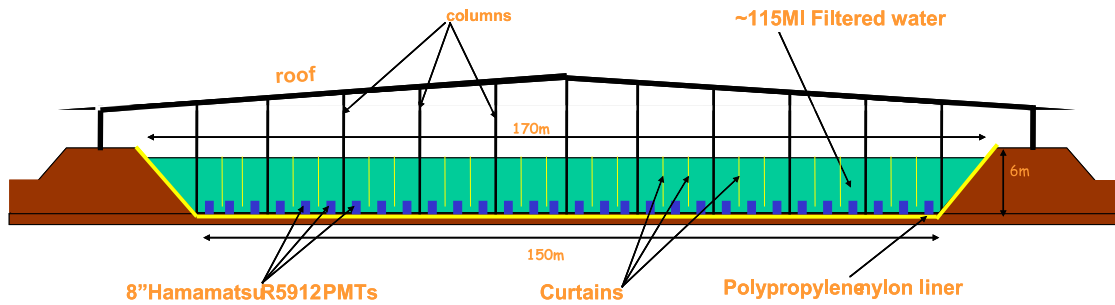


Fig. 11. HAWC schematic indicating location of PMTs and isolation curtains [57].

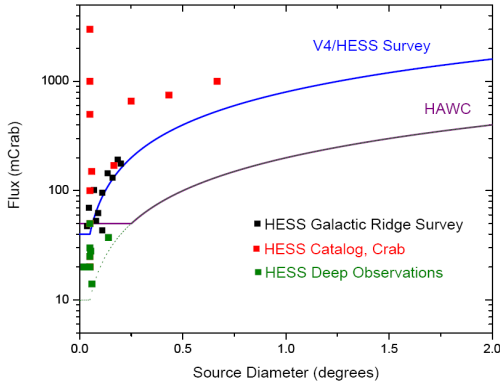


Fig. 12. Two year survey sensitivity of HAWC in comparison with several H.E.S.S. surveys. [57]

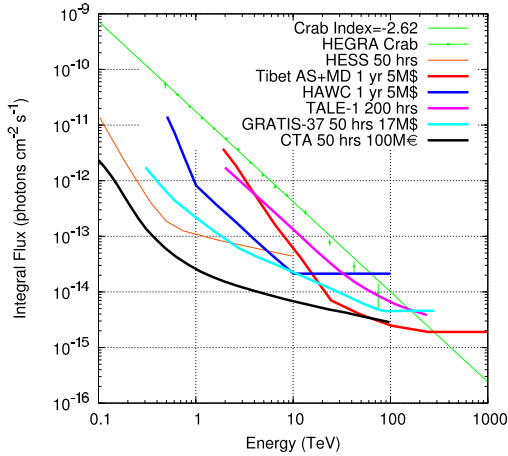


Fig. 13. Integral flux sensitivity of the proposed Tibet AS + muon detector (MD) array after 1 yr observation (red line).

studies, and a new γ -ray imager in the <100 MeV regime.

POLAR [61] is designed to measure the polarisation of γ -rays in the few keV to few MeV range. Its science focus is Gamma-Ray Bursts (GRBs) in which polarisation has been flagged a key discriminant of several models. The core of the detector is made up of a plastic scintillator array of 240×240 elements. Each element is optically isolated and 6×6 elements are combined to form a so-called bar. Determining the polarisation angle is based on the coincident detection of Compton recoil electrons and photons in bars of detectors. Vetos to reject CR triggers are incorporated. Suc-

cessful laboratory tests of a single bar have pushed the proposal of full space-borne mission. It is expected that POLAR will be able to detect polarisation fractions $\geq 10\%$ in those GRB with total fluence 10^{-5} erg cm^{-2} . Roughly 10 events of this type per year could be detected.

The three dimensional track imager (3-DTI) is aimed for 0.3 to 50 MeV γ -ray astronomy, and will provide an order of magnitude improvement in sensitivity over COMPTEL/CGRO. Suggested a concept for NASA's Advanced Compton Telescope, 3-DTI was outlined by [62] with the science case presented by [63]. 3-DTI is a large volume time projection chamber (TPC) with 2D gas microwell detector (MWD) readout. The TPC volume is bound by a drift electrode at the top, and by the MWD at the bottom. The ionisation tracks from Compton-scattered and/or pair produced electrons (resulting as γ -ray enter the TPC), drift down to the MWD and are reconstructed in 2D. The time profile of the tracks enables a 3D reconstruction. Such reconstruction for photons undergoing Compton scattering is that their arrival directions are reduced to an arc instead of a circle, thereby considerably improving the angular resolution (Fig. 14). Lab tests of a prototype version have been successfully carried out [64], paving the way for a balloon and/or space borne version.

Neutrinos – Gamma-Ray-Related Issues

The tight coupling between neutrinos and γ -rays was emphasised in several contributions in this session. In particular, the well-established γ -ray fluxes from H.E.S.S., EGRET, and others, permit predictions of the detection rates in current and proposal neutrino detectors. As well as this, several contributions provided status reports and plans for coordinated γ -ray/neutrino observations. For status reports see [1].

[65] summarised neutrino detection rates in KM3NeT (the proposed neutrino detector in the Mediterranean) based on H.E.S.S. Galactic source fluxes. A (Sybill-based) parameterisation of secondary pion and other particle production was used along with the suggested effective area of KM3NeT. Additional assumptions (not necessarily applicable to sources where leptonic emission

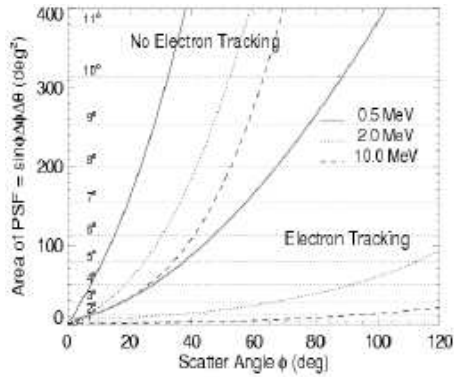


Fig. 14. Angular resolution (area and radius) vs. incident photon angle in the 3-DTI with and without electron tracking [63]. Results for several photon energies are shown.

is considered the most viable case) concerning the H.E.S.S. sources were that no non-hadronic component was present, the radiation density at the source was low, and there is a low magnetic field. The best signal to noise (atmospheric ν) ratios for 5 yr observation were indicated for the bright SNR RX J1713–3946 (2.6 to 6.7 source event over a background of 8.2) and the nearby plerion Vela-X (5 to 15 evnts over a background of 4.6). Many of the other H.E.S.S. source have fluxes a factor 5-10 lower and so present more difficult tasks. However, the assumption of low in-source radiation density would not necessarily apply to the compact binaries, leading to their γ -ray fluxes acting more as lower limits on the potential neutrino fluxes one could see. A key point is that given the generally hard source and soft atmospheric neutrino spectra, and detector effective area behaviour with energy, better signal to noise ratios are expected at higher energies > 5 TeV or so.

Based on the distribution of known SNRs, and gas in the Galactic plane, CR diffusion properties (propagation in turbulent magnetic fields) [66] presented calculations of the diffuse neutrino and γ -ray flux at different energies. Their calculation were able to match EGRET measurements in < 10 GeV regime, and provide considerably more narrow latitude distributions in the > 1 TeV regime. Their predicted neutrino flux in the Galactic Centre region for $E > 1$ TeV of $4.2 \times 10^{-11} \text{ cm}^{-2} \text{ sr}^{-1} \text{ s}^{-1}$ would appear difficult

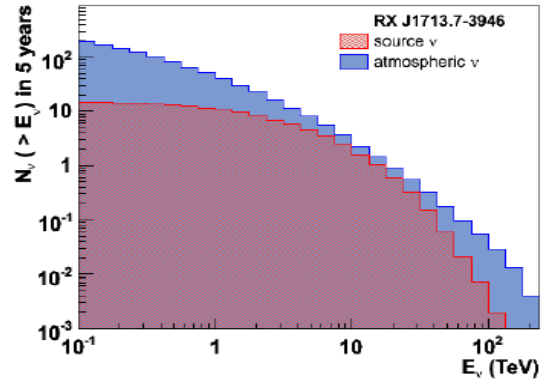


Fig. 15. Neutrino event count (in 5 yr) predicted from RX J1713–3946 (source ν) and atmospheric neutrino count vs. energy [65].

with KM3NeT, and hence require a CR enhancement.

[67] outlined the target of opportunity (ToO) setup between AMANDA-II and MAGIC. MAGIC γ -ray observations are triggered if AMANDA observes neutrino events close to pre-defined sources. The list includes AGN and X-ray binaries). Test observations on a few sources was carried out in Sept. to Nov. 2006 in order to assess the feasibility of such a programme. Email alerts are sent from AMANDA-II to MAGIC if any neutrino event is reconstructed with a few degrees of selected sources. MAGIC observations are carried out if possible within 24 h of the alert. The joint probability of observing n_ν neutrinos and n_γ γ -rays was assessed to ensure false alarm rate was not too high. n_γ is directly into p_γ , the probability to observe a particular γ -ray flare within the prescribed time limit. Effort is devoted to defining this term based on long-term monitoring of sources and presently upper limits are given. During the test run several alerts were given (on Mkn 421, 1ES2344+514, 1ES1959+615, LSI+61303,GRS1915+105) and no coincident γ -ray events or flares were seen.

In the opposite direction, using γ -ray flares to constrain time windows in neutrino detectors, [68] discussed the possibility of HAWC-triggered time windows in the IceCube detector.

Gravitational Waves

Gravitational wave detection was not a major theme at this conference and only two contributions were given. [69] outlined the fact that CR-induced charge on LIGO (designed for 10 Hz to 3 kHz gravity wave detection) optics could be a major source of noise (from charge motion and dust attraction) in its sensitive frequency range. Methods to mitigate this charge build up were discussed.

Conclusion

Some key conclusions on these sessions primarily devoted to the detection of γ -rays and neutrino can be outlined as follows:

- Ground-based γ -ray astronomy is a now a mature field employing two established and complementary techniques (a) (Stereoscopic) Imaging Atmospheric Cherenkov Imaging; (b) Water Cherenkov detection of air shower particles. All of the planned and proposed detectors appear to be making use of at least one of these two techniques.
- The next step beyond H.E.S.S., VERITAS, MAGIC-II etc.. is taking shape via continental-wide organisation efforts such as CTA (Europe) and the WhitePaper (USA), along with several other proposals. This is necessary in order to gather community-wide support for the required funding scales of order 100 Million dollar/Euros.
- GLAST is ready to go and its launch date is not far away. GLAST will no doubt provide a fresh and clearer look at the MeV to GeV Universe.
- Neutrino event rates in forthcoming detectors (IceCube, KM3NeT) appear to be a few per year from the strongest γ -ray sources. This would give them a chance to realise discovery of extraterrestrial neutrino sources. In addition the first efforts in coordinated neutrino/ γ -ray observations have begun.

I wish to thank the organisers of the 30th ICRC for giving me the opportunity to summarise these

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