A conceptual design of an advanced 23 m diameter IACT of 50 tons for ground-based gamma-ray astronomy

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***Abstract*. A conceptual design of an advanced IACT with a 23 m diameter mirror and of 50 tons weight will be presented. A system photon detection efficiency of 15-17%, averaged over 300-600 nm, is aimed to lower the threshold to 10-20 GeV. Prospects for a second generation camera with Geigermode apds will be discussed.**

***Keywords*: Ground-based γ-ray astronomy, Cherenkov telescope**

I. Introduction

The window of very high energy (VHE) ground-based gamma-ray astronomy was opened 1989 by the Whipple collaboration observing TeV gamma-rays from the CRAB nebula [1]. In the following 20 years this research field developed with a breath-taking speed, and up to now more than 70 sources have been discovered and many new and fundamental physics results attained. The success was mainly achieved by improving the so-called imaging atmospheric Cherenkov telescopes (IACT), i.e. by making it possible to detect Cherenkov light from extended air showers generated by cosmic particles in the upper atmosphere. One of the clear messages from the current results is that further progress can be made if detectors are further improved. The main goals are lowering the energy threshold from currently about 50-60 GeV down to close to 10-20 GeV, and to increase the sensitivity by a significant factor compared to the currently best instruments. The sensitivity can be raised by two methods: a) by increasing the photoelectron detection rate from showers, thus improving mainly the gamma/hadron separation, and b) by operating many IACTs in an array configuration, i.e. by stereo observation along with a significant increase of the collection area. Another goal is to achieve a significant overlap in energy with the FERMI satellite [2]. Here we present a conceptual design for a next generation IACT with improved performance, which could be the basic element for the above mentioned goals. Additional aims are the rapid positioning which will permit observations of GRBs in near real time after a satellite alert, and extending the observation of strong sources in the presence of moonlight. Using such a telescope in an array configuration should allow one to achieve a significantly higher sensitivity. In the following, we will mention only some of the currently most important questions in the area of fundamental physics studies and searches for new gamma-ray sources:

- Dark matter searches
- Quantum gravity studies, i.e. searches for possible Lorentz invariance violation
- Study of the extragalactic background light (EBL)
- Searches for topological defects
- Study of the upper energy range of GRBs
- Study of the upper energy range of pulsars
- Search and studies of high red-shift AGNs
- Studies of flaring AGNs and AGNs in their 'low' state of emission

Obviously, the program will be much richer because of the increased discovery potential for new sources due to improved sensitivity, but the scope of this contribution has to be limited to the above mentioned topics. Although there is partial overlap with FERMI, most of the studies require sensitivities above $\approx$ 30-50 GeV to be orders of magnitude higher than what can be achieved with FERMI.

II. The basic telescope concept

The basic design is a derivative of the MAGIC telescope [3], but with a much larger mirror area, lower weight and a number of technical improvements. Fig. 1 shows a conceptual drawing of the alt-azimuth telescope with a 23 m diameter parabolic mirror and an f/D of 1.2. The weight of the moving part of the telescope will be only 50 tons in order to allow rapid rotation. Such a low weight can be achieved by using for most of the mount carbon fiber reinforced plastic (CFRP) tubes, low weight mirror panels of $\approx$ 2 m^2 area and compact undercarriages running on an I-beam serving also as an anchorage against liftoff of the telescope during strong storms. The telescope will follow the 'semisoft' design of MAGIC, i.e. correct small deformations of the structure during source tracking and caused by temperature changes by using an improved active mirror control and also an active camera support mast control (see below).

A. The lower mount and the mirror support structure

The telescope is a so-called alt-azimuth design running on 6 undercarriages on a circular I-beam fixed with a number of steel bars to the central axis. The

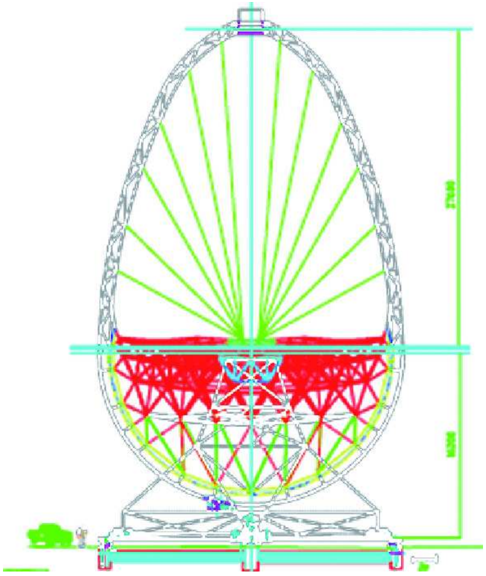

Fig. 1. Layout of the 23 m telescope (P. Sawallisch)

azimuth structure resembles very much the configuration of MAGIC but uses large diameter high strength CFRP tubes, which can now be produced in series by industry. The bogeys will be very compact and a factor 3 lighter compared to the MAGIC ones. For the main mirror support dish a modified configuration of the tubular construction will be used. The formerly used basic element of a pyramid shape will be replaced by a significantly stiffer tetraeder configuration, thus allowing a stiffer spaceframe for the 23 m diameter support, but using the same length of tubes compared to the MAGIC construction. The spaceframe will be a 4-layer configuration. The CFRP material is considerably more expensive than steel, but a large weight saving, lower transport and installation costs and much lower drive costs, eventually will balance the steel construction costs. CFRP has, besides a much lower weight, two other advantages: a) the thermal expansion is nearly zero; thus dish deformations due to temperature changes are small, and b) the material has a much higher oscillation damping, thus permitting the use of longer tubes of a smaller diameter. In total, the construction will use about 2000 m tubes of 80 or 100 mm diameter for the space frame and about 600 m of 250 mm diameter high strength tubes ($>$1000 tons breaking resistance when pulling and $>$130 tons buckling strength) for the azimuth structure. A drive system similar to that of MAGIC will be sufficient because of the lower weight of only 50 tons compared to MAGIC's 70 tons.

B. The mirror and active mirror control

The 420 m^2 mirror will be composed of 210 panels of 2 m^2 each. The gross mirror profile will be parabolic to minimize any additional time spread of the Cherenkov light flash. Because of their size the mirror panels have to be aspheric. Two options for the mirror production are under discussion: a) use of diamond turned panels which can now be fabricated with the shape of an off-axis paraboloid, b) the replica technique using cold slumped glass-aluminum Hexcell core sandwiches. By using aspheric negatives it is also possible to make the replicas according to the required shape on the mirror dish position. The mirror panels will have a hexagonal shape to fit the tetraeder elements of the space frame. A panel weight of $<$ 20kg/m^2 is aimed for. For further details see [4]. As mentioned, the semisoft design concept requires active corrections of the panel orientations. It is planned to have a permanent control. Two options for monitoring the orientation are under evaluation: a) infrared laser beams mounted on the mirror panels and pointing to diffuse reflectors mounted asides the camera but not seen by the IR insensitive camera photosensors; the laser spots will be consecutively observed by an IR sensitive CCD camera and deviations from the nominal positions determined and corrected accordingly, and b) small CCD cameras on all mirror panels will observe reference LEDs (mounted in the focal plane outside the camera) and determine the deviation of the reference orientation and initiate corrections. The latter solution is more complex and more expensive but allows for higher flexibility.

C. Camera and camera support mast

It is planned to use a camera of 4° field of view (FOV), subdivided into pixels of 0.07° diameter (hex entrance pupil), i.e., comprising around 2600 pixels. The camera will be placed in the focal plane at 27.5 m distance from the dish. This poses a major challenge for the construction of the camera support mast. As for MAGIC, it is intended to use a single arc support mast of only 2-3 % shadowing of the main mirror. Because of the large distance in f and the heavy camera the mast will have a back-to-back structure of two tubes spaced by 80 cm. In order to avoid transverse displacements of the mast, as well as oscillations, the masts will be fixed in place by a number of high strength ropes made from either Dyneema (about 15 times stronger than steel for the same weight, need UV protection) or Carbon fiber rods (used in the deep sea oil industry, about 5 times stronger than steel for the same weight). In order to correct for mast bending at large zenith angles we will use an active bending correction by pulling the cables with actuators for the necessary mast correction.

The baseline pixel units will comprise a hemispherical 1" photomultiplier with a 'super-bialkali' photocathode and a light catcher lined with a dielectric reflector foil of $>$ 96% averaged reflectivity between 290 and 700 nm. For low aging and operation during partial moon light the PMT will be operated at low gains of 2-3.10^4 followed by a high bandwidth, low noise preamplifier of at least 20-26 dB gain. The PMTs will be treated to maximize the photon detection efficiency (PDE) by a) optimizing light collection by the PMT front window using either a frosted glass or a diffuse lacquer, and b) by maximizing the voltage between photocathode and first dynode to increase the photoelectron collection efficiency and to minimize time spread in the front-end electron optics. The camera will be sealed by a UV transparent front window of very low reflectivity (broadband antireflective coating or plasma-etched surfaces). It is estimated that the combined use of the above noted changes will improve the light-to-photoelectron conversion by about 25-38% compared to a standard pixel configuration of frequently used flat window bialkali PMTS. An overall PDE of 15-17 % of the incident Cherenkov light between 300 and 600 nm should be achieved. Besides the baseline configuration quite a few other photosensor options are under evaluation; see also below about a second generation camera with G-apds. A possible option might be the use of multipixel flat panel photosensors like the ARCALUX proposal because of the potential of lower prices [5]. A critical issue is the question of how much or if all the DAQ and trigger electronics will be placed also in the camera. On the one hand, one will have a very compact arrangement, while on the other hand, one has to pay the heavy penalty of a substantially heavier camera and serious cooling problems. Also servicing and mid-life updates are difficult. Increasing the weight of the camera will require a much more reinforced and heavier support structure, which, in turn, will require a significantly heavier mount construction, thus missing by a sizeable margin the 50 ton weight goal. An alternative might be converting the PMT signals back to light by VCSELs and rout the optical analog signals by optical fibers to an easy accessible place at ground. This worked very well for MAGIC, where it was possible to change the DAQ and to add a new trigger logic already after 4 years of operation thanks to the rapid progress in electronics and computer power. (It should be noted that from the time of constructing MAGIC until today the computer power and the data storage capacity have improved by a factor of at least 50). The two options are still under discussion, and a careful evaluation has to be made of the extra costs for the optical fiber system and the cost saved by using the considerably lighter and simpler mechanics, the reduced cooling and the easier access and servicing. The new generation VCSELs have a much lower noise and less mode hopping compared to the ones used in MAGIC. Tests have shown that the VCSEL signal can be stabilized over a temperature range of 70 ° C. All optical fibers can be bundled in 26 cables, each of a thickness of a RG 213 coax cable.

D. The trigger and the DAQ

It is expected that the night sky light background will generate a single photoelectron rate of 150-200 MHz per pixel when viewing a sky section outside the galactic plane. Observing objects on the galactic plane or during partial moon light will result in significantly higher rates. Therefore, an efficient trigger system is needed to select possible signals from air showers. In the past, the readout speed of the DAQ and the control computer were demanding a high trigger selectivity to reduce the rate to below 1 kHz. Assuming that Moore's law still holds in the coming years one can expect another factor of 50 increases in computer power and a similar drop in the price of storage elements. Concequently, one can envision a rather simple trigger logic resulting in a rather high rate. An easy solution for the readout would be the use of many processors reading out only small camera sections and storing the data in large raid discs. An additional computer farm can process the raw events and reject quickly the large number of accidental triggers while selecting a few specific patterns of event candidates. This event selection might continue over daytime to allow for a slower processing than the initial trigger rate. In summary, the progress in computer power would allow to roll over complexity of costly hardware trigger logic to a much more powerful and flexible software trigger logic. The hardware trigger logic could be similar to the SUM trigger used by MAGIC for the CRAB pulsar study [6]. To suppress accidental triggers from large amplitude afterpulses, clipping before summing can be used [7]. As current PMTs have a pulse width equal or below the time structure of low energy showers of $\approx$ 2-3 nsec, a digitizing system of at least 1 GHz sampling rate is needed if one wants to use timing and narrow signal windows for the NSB reduction. Such systems are now available in the form of switched capacitor arrays. An example is the DRS 4 chip developed at the PSI [8]. This chip with 1024 capacitors can be clocked up to 6 GHz and can record signals of 1-3 nsec width with a dynamic range of $>$ 66 dB while having a power consumption of $<$ 100 mW/channel.

E. Some rough performance estimates

In the absence of fully-fledged MC simulations one can extrapolate some performance from smaller size IACTs. A threshold of 20-30 GeV is estimated for the normal source search and $<$ 15 GeV for pulsar studies. The sensitivity of a single 23 m IACT possessing the above parameters should be below 1% of the Crab flux for a 5 σ signal and 50 h observing time, while an array of 9 should reach a sensitivity of 0.5-2 milliCrab.

F. Price and construction time

The price is very much a function of the number of telescopes. While a single telescope might cost around 8 M Euro, the price per unit for a small series production should be 5-6 M Euro, with about 1/2 of such amount being spent on the mount and mirrors, and the other half on the camera, trigger and readout. Assuming early prototyping the construction of a single telescope should take around 2 –3 years, while a small series production of e.g. 9 units would require twice the time.

III. A SECOND-GENERATION CAMERA

In the long run it might be possible to replace the PMTs by solid-state Geigermode-avalanche photodiodes

(G-apd). These very compact photosensors have the potential to double the PDE when folded by the Cherenkov spectrum and the telescope's optical parameters, i.e. it should be possible to lower the threshold to close to 10-15 GeV. First tests of detecting Cherenkov light flashes gave encouraging results [9]. G-apds need only a low operation voltage ($<$100 V), no magnetic shielding, show no aging and can be exposed fully biased to daylight without destruction. It is estimated that 2-3 more years of development will be needed to reach a high maturity level. Current weaknesses are the small area, a high price, and some operation deficits in optical cross-talk, drift of the PDE as a function of temperature and bias voltage, and insufficient UV sensitivity below 400 nm, see [10], [11].

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