Status of the DWARF project for long-term monitoring of bright blazars

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***Abstract*. In the past years, the second generation of imaging air-Cherenkov telescopes has proven its power detecting weak sources with high sensitivity and low energy threshold. Scanning the sky for unknown sources and investigating weak sources, not much observation time is left for long-term studies, necessary to understand the currently unpredictable flaring behavior of blazars.**

For this purpose, presently one of the former HEGRA telescopes is revived and its technology is upgraded. Apart from a new drive system and an increased mirror area, it is the first time a Cherenkov telescope will be operated using semi-conductor based photo detectors (Geiger-mode APDs) for its camera. The camera is currently developed in the FACT-project and promises a considerable increase in sensitivity and decrease in energy threshold, compared with a classical photo-multiplier based camera.

In this presentation, a technical overview is given, and the status of the project is outlined.

***Keywords*: IACT, Monitoring, VHE, DWARF**

I. INTRODUCTION

The variability of very high energy (VHE) gamma-ray emission from blazars, ranging from years down to minutes scales [1], is the key to understanding both, the central engine of AGN and particle acceleration within their plasma jets. Deep investigations with multi-wavelength coverage performed on short timescales as done by all recent Cherenkov telescopes, such as MAGIC [2], VERITAS [3], H.E.S.S. [4], and CANGAROO-III [5], are mandatory for modeling the spectral energy distribution (SED) of the sources. Although the Synchrotron Self Compton (SSC) model [6] is very successful in describing most of the observed SED, it fails in explaining the observed “orphan” VHE flares (lacking a X-ray counterpart) [7], [8], as well as the SED of the Flat Spectrum Radio Quasar 3C279 [9], giving rise to the assumption of hadronic acceleration models as proposed in e.g. [10], [11]. Additionally, these models predict the emission of high energy neutrinos, which might be detected with the Neutrino observatory IceCube [12]. To enhance the sensitivity of those neutrino observations, cross-correlation to VHE gamma observations can be used. But for this, complete data samples for both messenger particles are mandatory [13]. Also, the investigation of periodical behavior as observed in Mrk 501 [14], possibly connected to a binary black hole system as central engine [15], cannot be performed on the common deep but sparse observations. For these reasons, it is obvious that there is a need for monitoring observations, at least for the VHE brightest blazars (for more details see [16]). Actually, there are ongoing monitoring observations with MAGIC [17], [18] and Whipple [19], but they are far from being complete. As the latest generation Cherenkov telescopes are overbooked with observations at their sensitivity limit or deep multi-wavelength observations, it is obvious that no more precious observation time of these instruments can be

Fig. 1. Artistic view of the finsihed DWARF telescope

assigned to time-consuming monitoring observations – this is the starting point for the DWARF network, first proposed in [20].

Presently, one of the former HEGRA telescopes, still located at the Roque de los Muchachos on the Canary Island of La Palma, is being revived as DWARF (Dedicated multiWavelength Agn Research Facility) in a completely refurbished way [21]. It will be dedicated to monitoring observations as motivated above. The following gamma bright blazars will be monitored on a nightly basis: Mrk 501, Mrk 421, 1ES 1959+650, H 1426, 1E 2344, and PKS 2155-306. To monitor the performance of the telescope, critical for long-term observations, also the Crab Nebula will be observed. Taking this into account, the visibility of these sources is distributed uniformly over the year.

The following sections present an overview of the technical enhancements of the new telescope and give an outline of the project status.

II. HARDWARE UPGRADE

A. *Drive*

To allow for easy maintenance, industrial components have been chosen to replace the old drive system based on stepping motors. Similar to the existing drive systems of the two MAGIC telescopes [22], which are identical since an upgrade at the end of April, new servo motors with corresponding motion control units have been bought. Since the old planetary gears would not have resisted the increased momentum of these motors, they have been equipped with new planetary gears. The existing worm gears are made for such demands and are still far from their nominal life time. As the telescope is planned to be operated remotely, it will be the first robotic Cherenkov telescope in the world. So for safety reasons, a bevel gear with a continuous shaft has been mounted between motor and planetary gear, at which a crank can be attached for manual movement in emergency cases. For the control of the system, a PLC (programmable logic controller) has been bought. The final goal is to implement all astrometric algorithms necessary to track sky positions into the PLC, so that no controlling PC is needed anymore. Until then, the PLC program and the control software from the MAGIC telescopes can be used with minor changes accounting for the simplified system.

At May 2009, all components are already bought and assembled and will be shipped soon.

B. *Reflector*

The existing mirrors of the former HEGRA CT3, being round (d=60 cm) and composing a reflective area of 8,5 m^2 have been exposed to sunlight and harsh weather condition for more than fifteen years and show severe aging effects. Thus, they will be replaced by the all-aluminum mirrors developed for the upgrade of HEGRA CT1 [23]. These have a hexagonal shape around an in-circle with d=60 cm and by this compose a roughly 10% larger reflective area than the former ones. Additionally, they have recently been re-machined and re-coated. Measurements of the focal length of each individual mirror show that now the standard deviation around the desired focal length of 4.90 m is only 2 cm. Measurements of the reflectivity and of the point spread function are ongoing and show promising results exceeding their original performance. Fixtures for mounting these mirrors on the existing telescope mount have already been built and shipment and installation will start directly after finishing the measurements.

C. *Polymer mirror development*

Finally, the reflective area is planned to be increased from $\sim$10 m^2 to about 15 m^2. Therefore, a new type of mirrors is under investigation. These mirrors will be copies from a negative master. The used polymer promises to copy the surface roughness in the order of a few nanometers, which is precise enough, that the copy only needs a reflective and protective coating. Besides the use of this technique for light guides in balloon flight experiments a few years ago, mirrors with the specification fitting our needs will be produced to prove their suitability. For this purpose, a negative has been produced made of glass and first prototypes of copies are currently manufactured. First results are expected at the end of summer.

D. *Light Concentrators*

To increase the sensitive area of photon detectors and to reduce the amount of diffuse light from the night-sky hitting the detector, light concentrators are used. Several concepts for such reflective cones are currently compared [24]. Since the photon detectors in the case of semiconductors have a square shape and the preferred shape of a pixel is hexagonal, to maintain equal distances to all neighbors, the shape of the reflective surface has to be adapted. Therefore, simulations have been carried out and first prototypes have been manufactured. Among the classical hollow cones, also solid cones are under investigations. For a first prototype module, each square pixels (photon detector) has been equipped with a square cone, made of straight reflective foils. Manufacturing of better shapes, like the classical tilted parabolic shape, and glass cones for the final camera are under investigation.

E. *Photon detectors*

As photon detectors, Geiger-mode avalanche photodiodes (G-APD) have been chosen [25]. G-APDs are divided into single cells, each of them an Avalanche Photo-Diode operated in Geiger-mode. In this mode, the applied bias voltage is above the so-called breakdown voltage where the avalanche process is self-perpetuating. The avalanche started, for example, by an incoming photon generating an electron-hole pair, is stopped by lowering the bias voltage below the breakdown voltage by either a serial quenching resistor or an active circuit.

Since G-APDs are pure semi-conducting detectors, they are compact and light-weight. Furthermore, they are operated with a relatively low voltage (∼70 V) compared to the high voltages needed to operate photo-multiplier tubes (PMT). This allows to build a camera, easier to operate and maintain. The small size and their low power consumption also simplifies temperature control, compared to PMTs, necessary to maintain their performance.

F. Prototype Camera

A prototype camera has already been assembled [26]. It is made out of 144 G-APDs arranged on a square grid. The signal of four G-APDs is summed together, forming a pixel. Mounted at the focal plane, the pixel diameter corresponds to roughly 0.15°.

The front plate holding the G-APDs will be actively cooled to maintain a constant temperature for all light detectors. This is necessary to keep the dark current well below the unavoidable accidental rate due to photons from the night-sky background and to avoid hight gain variations due to temperature changes. Furthermore, the gain depends on the applied voltage, hence, the voltage is actively stabilized. Since the gain is also changing when the G-APD is exposed to higher photon fluxes, e.g. the light of the rising moon, an online correction is foreseen. To keep it stable, a feedback is implemented to adapt the applied voltage accordingly. Therefore, the amplitudes of signals from a pulsed LED are evaluated. First tests have been carried out in the lab and have shown promising results [26].

G. Readout

For the protype, the readout scheme looks as follows.

After signal pre-amplification and shaping, the signal is transmitted by coaxial cables. After splitting into a trigger and a readout branch, and an emitted trigger, the signals are digitized at 40 MHz with 12 bit by reading them out them from DRS2s (Domino ring sampler, [27]). Storage in the ring buffer can be initiated with rates between 0.5 GHz and 4.5 GHz.

Finally, the data are stored by a single board computer.

Lab tests of the full system will be finished by the beginning of summer. Afterwards, the electronics and the prototype will be shipped to La Palma for first field tests of a G-APD camera.

H. Simulations

To compare and estimate the sensitivity and energy threshold of different possible setups, simulations are mandatory. They will also be needed later in the analysis of the data. Since existing detector simulations are not flexible enough for a design study, a new detector simulation has been implemented [28]. Therefore, the existing modular framework *MARS - CheObs ed.* [29], [30] has been chosen which will also be used for data analysis as soon as data is available.

With the current simulation, images of the prototype module were produced, which can be compared with real data as soon as the system is fully set up.

Simulations of a fully assembled system show that, with nowadays analysis methods, a trigger threshold below 450 GeV is feasable if no major unexpected behavior of the electronics is revealed during the prototype test.

Usually, the main background at low energies for a monoscopic Cherekov telescope are images of muons with incident points outside the Reflector, which give small and lengthy images easily confusable with images from gamma induced showers. Muons hitting the reflector directly will produce ring like images due to their parallel light emitted in the Cherenkov cone. If the muon misses the reflector, only a part of the ring is imaged. In both cases, the light yield along the ring is linearly dependant on the light collecting area of the reflector. The radial light distribution is mainly determined by the optical point spread function of the reflector.

Since a few small mirror segments can be manufactured with high optical quality and a small reflector allows for almost perfect alignment, muon rings, and parts of them, are smaller than typical gamma showers. Hence, having a high resolution camera, muon suppression should be easily possible.

Furthermore, a parabolic, i.e. isochronous, reflector will maintain the time information. Having a high enough resolution at the readout, muons can easily be suppressed by their extremely small (<1 ns) time profile compared with gamma induced showers (∼3 ns).

Corresponding to the relatively low energy threshold for such a small telescope, a quite good sensitivity has been estimated. This could be achived by improvements in light collection efficiency due to better reflectivity and photon detection efficiency. Also in data analysis, background suppression could be enhanced, mainly because of the use of signal timing [32]. The simulations confirm a sensitivity in the order of HEGRA system.

III. OUTLOOK

A. From a prototype to a camera

First tests showed that all channels are working properly and the give the expected results. More tests to understand the system are in progress, including investigations of the gain stability, mechanical stability, long-term stability, and the behavior under bright light, e.g. moon light.

To prove the stability under typical environmental conditions at night, a climate chamber is used to simulate typical temperature gradients, or humidity.

After these test are finished at the beginning of summer, an installation for a test phase on the DWARF telescope is planned.

In case of success, the development of the electronics for the final camera will start. First specification are currently defined.

B. The world wide network

To overcome limitations both from weather conditions and from nightly observation time which introduces a biased sampling, we are initiating a global network of

Cherenkov telescopes, operated in a coordinated way for monitoring observations of nearby blazars – the DWARF (Dedicated Worldwide AGN Research Facility) Network. The aim is to distribute several Cherenkov telescopes around the globe to be able to perform 24/7 monitoring of the most interesting sources, preferably with temporal overlap and redundancy to account for weather and duty cycle constraints. By this, multi-wavelength observations of the monitored sources, as already agreed upon with the Metsähovi Radio observatory [31] and the optical KVA telescope [33], will no longer be limited by the low duty cycle ($\sim$10%) of Cherenkov telescopes. Up to now, there are already several telescopes participating in this network: Apart from the presently built DWARF telescope on La Palma, the Whipple 10 m-telescope (Mt. Hopkins, USA) [34] and the TACTIC telescope (Mt. Abu, India) [35] will continue their monitoring observations, dovetailing with the observations of the DWARF telescope. Additionally, two of the former HEGRA telescopes will be built up in Mexico and join the monitoring as OMEGA [36] in the near future. Furthermore, two of the former telescopes of the Telescope Array have been deployed in Utah, waiting for new imaging Cherenkov cameras to contribute to the monitoring as Starbase Utah [37]. There are also plans and prospects for an additional Cherenkov telescope to be built in Romania. Further details on the present status of this already initiated network are outlined in [16].

IV. CONCLUSION

A first prototype module of a novel camera using Geiger-mode avalanche photo-diodes has been built. The module is currently successfully under investigations in the lab. Field test will start soon after May 2009.

The infrastructure of the telescope, mainly mirrors and drive, is ready for shipment and will be installed soon.

Furthermore, simulations give promising results, which predict a success of the planned physics program.

Since the final goal is long-term monitoring of the brightest blazars, contact to other groups building or having monitoring facilities, like the Whipple 10 m, have been established. First agreements were made.

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