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Status of the 17 m diameter Magic telescope

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Abstract. A collaboration of 14 groups is currently building a 17 m diameter imaging Cherenkov telescope, dubbed MAGIC telescope. Most of the components are already built or are shortly before completion. The telescope will be installed on the Canary island La Palma at the Roque de los Muchachos. A technical progress report with emphasis on the latest developments will be given. In addition, perspectives for the phase II will be presented.

1 Introduction

Very high energy, groundbased gamma-ray (short γ) astronomy with large imaging Cherenkov telescopes has demonstrated by many exciting results in the last decade that this technique has a big potential for the new field in astroparticle physics research. Currently, there exists an observation gap between, say 20 GeV (upper limit of satellite borne detectors) and about $250 - 300$ GeV (lower limit of present groundbased telescopes). While present day telescopes are only able to observe sources of the nearby universe the new, low threshold, high sensitivity detectors exploring this energy gap might allow one to observe the γ sky up to about a redshift of nearly 3. One such project, the so-called MAGIC telescope (MAGIC phase I, i.e. with a camera comprising classical photomultipliers), is under construction by an international collaboration of 14 institutions. MAGIC is a single 17 m diameter air Cherenkov telescope employing many novel technologies. The original project is described in a detailed design report (**?**) and was presented during the last ICRC (**?**). The physics goals have also been described extensively in various reports. As the project is now fairly advanced in its construction, an update of the changes with respect to the design report, respectively a status report will be given. In the second main part of this paper the perspectives, respectively new developments for MAGIC phaseII will be presented.

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2 Status of MAGIC

The essential geometrical and performance parameters of the MAGIC telescope are the same ones as outlined in the design report. The telescope will be set up inside the HEGRA site on the Roque de los Muchachos (28.8 N, 17.8 W, 2250 m asl). The agreement for the site use was signed in June 2000 with the IAC and CCI. For the construction permit for the foundation we encountered some problems because of the installation in the so-called 'preparque' area of a national park but now only minor administrative actions are needed and it is expected that the pouring of the foundation will take place at the time of the conference. Contrary to the HEGRA installation there will be a permanent large centralised counting house, housing also a small optical telescope.

The design and fabrication of the entire telescope structure has been completed at the company MERO and is awaiting transport to La Palma in early June. Material tests of the carbon fiber tubes for the space frame have revealed that the strength is higher than originally anticipated (safety factor > 5 for the critical glue joints). The geometry of the mirror support space frame has been slightly changed from the original 'basket' version, to a smaller diameter multilayer spaceframe structure. By this change the number of tubes could be significantly reduced without compromizing in deformation. The mirror support dish weighs 5 tons. The MERO mounting principle allows for a quite fast assembly. This has been demonstrated for a 5% section assembly within 5 hours. The Azimuth undercarriage section of the telescope is now made from steel (instead of aluminium) due to the need for some increase in weight to guarantee stability in strong winds. In case of extreme storms, the telescope can be anchored in one of six azimuth positions to the 400 ton concrete foundation. The entire telescope weight is slightly below 40 tons. The telescope has 6 bogeys, two of them driven by 10 kW servomotors. The declination movements are controlled by a third motor. Detailed analysis of the mechanics showed that the telescope could be positioned to any point on the accessible sky in less than 20 sec when using optimised control software. This rapid response is needed in case of GRB alerts.

Tracking control is based on shaft encoders ($0.04°$ precision) augmented by a starguider to better than $0.01°$ precision. The range of allowed movements are $405°$ in azimuth and $+100°$ to $-80°$ in zenith angle.

The production of the newly developed diamond turned, lightweight, all-aluminium mirrors is proceeding according to the plans (the funding flow requires that a certain fraction of the mirrors can only be paid in 2002). The development of the mirrors underwent many iterations. Best optical quality was found for mirrors using the alloy AlMgSi0.5 giving a reflectivity of typical 91% after surface treatment (anodisation or quartz coating). The alloy is rather soft and difficult to machine; therefore we settled for the alloy AlMgSi1.0 resulting in slightly lower reflectivity of $88 - 89\%$. The weight of a typical 49.5x49.5 cm production mirror is 4.0 kg. Mirrors have a typical point spread function of $1.5 - 2.0$ mrad (FWHM) when illuminated by a 3 mm diameter point source at 34 m distance. For normal prevention of dew or ice deposition (in winter), the mirrors are heated. The maximum power consumption for the entire mirror is 13 kW under normal operation.

Due to cost and weight restrictions the 17 m diameter mirror support dish could not be made infinitely stiff. Residual bending requires active mirror adjustment for permanent focussing.

For the active mirror control (AMC) eventually an in-house solution has been developed consisting basically of a stepper motor and a precision ballspindel with a setting error of 20 micron. Each motor (2 for a panel carrying four pre-adjusted mirrors) can lift up to 60 kg, i.e. 6 times more than normally required. The control software is rather complex and still not completed because we want to eventually adjust many panels simultaneously.

The camera FOV has an overall diameter of $3.9°$ and comprises an inner, fine pixelised section of 396 photomultipliers (PMT) of 24 mm diameter (with Winston cones corresponding to $0.1°$ size) and an outer coarser section of 180 PMTs corresponding to a $0.2°$ size. The PMTs have true hemispherical cathodes and only 6 dynodes for optimal timing, photoelectron collection and low gain. The company Electronic Tubes developed the PMTs according to our specifications. With specially shaped Winston cones it is possible that the trajectory of photons often passes the cathode twice, thus increasing the quantum efficiency (QE) by $15 - 20\%$. The PMTs are operated at around a gain of $1.5 - 2\text{x}10^4$ in order to reduce ageing and to allow for observations during moonlight. The PMTs are followed by fast, AC coupled transimpedance amplifiers followed by the optical analog signal transfer with multimode glass fibers to transfer signals to the central counting house. The camera is housed in a containment of 50 cm height and 145 cm diameter, and total weight is around 280 kg. About 800 Watts of heat are generated by the circuits, requiring additional cooling of the camera housing. The camera can be displaced by up to 30 cm to cope with special operation conditions and mirror adjustment requirements. For the focal length of 17 m the camera is quite far above ground and prone to wind interactions. According to simulations, a wind gust of 5 m/sec change in velocity should initiate a strongly damped oscillation of at most 4 mm displacement. A CCD camera will monitor these movements for later software correction.

The optical links have caused some problems. While the bandwidth of the system was more than adequate for the transmission of the fast PMT signals, the amplitude stability is just at an acceptable level. The laser diodes (VCSELs with 850 nm emission) sometimes show modehopping resulting in a few $\%$ gain jumps which cannot be fully calibrated out by test pulses. Eventually, the current multimode VCSELs have to be replaced by monomode VCSELs which are dropping rapidly in price, respectively by units with internal fast photodiodes allowing for a feedback driving circuit. The optical fiber cables (10 units of 16 mm diameter each) contain each 72 multimode fibers of 50 micron core and 125 micron cladding. As connectors the Diamond E2000 system has been adopted. This rather expensive system gives very reproducible values and has an integrated safety flap (Class 3B lasers are used). Signal attenuation and distortion over the 170 m cables are found to be minimal.

As digitizers a 300 MHz FADC system designed by the University of Siegen, has been adopted. A special challenge is the readout (via multiple independent PCI busses) in order to sustain a normal trigger rate of up to 1kHz. As trigger, a multilevel concept will be used. Level 0 (discriminators and a simple majority coincidence) is rather easy to implement. The backbone is formed by the level 1 trigger processor (based on FPGAs) allowing for next neighbour triggers of freely selectable multiplicity level ($2, 3, 4$ ..neighbours) and pattern. The exact configuration of the level 2 trigger (topological trigger) will be implemented in part on level 1 type units or by the addition of dedicated NN triggers once real data are available. The trigger will fetch information only from the inner part of the camera ($0.8°$ radius). According to MC studies using the latest shower simulations and telescope parameters and correct pulse superposition, we expect for a fourfold next neighbour trigger of 6 nsec width and a pixel threshold of 3.8 photoelectrons a threshold around 30 GeV. For a more conservative trigger with a pixel threshold of > 4 photoelectrons and neglecting the gain due to the improved Winston cones we expect a threshold around 45 GeV (see contribution O. Blanch, OG 2.05). For specific pulsar studies, the trigger area will be restricted to the inner camera section of $0.5°$ radius. This area will be equipped with selected higher QE PMTs and the trigger condition will be relaxed. See related contribution by F. Fonseca at this conference. For the pulsar trigger we expect a rather flat dependence on the energy with a maximum close to $12 - 15$ GeV and a sizeable number of triggered events below 10 GeV. The trigger studies and the search for new concepts are still ongoing.

The software developments are fairly advanced. Simulated events can be processed by the current version of the data reconstruction chain. As mentioned above, the MC simulations are permanently refined taking all available detector parameters as well as atmospheric parameters into account. Many efforts concentrate on the understanding of the muon and cosmic electron background which seem not to cause major problems.

The costs of the telescope are (under the assumption that no late overruns or unexpected extra needs occur) around 3.5 M $ (only investments, no infrastructure included).

3 First Light and start of the physics runs

About 3 years ago the date for the 'First Light' was set to mid 2001. This decision was based on the assumption that the very many technical developments could be successfully completed in time and the funding flow was adequate. Unfortunately, some technical problems have been encountered when planning production in industry (most of the components of MAGIC were designed in close collaboration with industry for later industrial production). Also available workshop capacity in most participating institutes was limited because a large demand for HEP experiments. In addition, a substantial amount of the funding was only released last fall. 'First Light' will be delayed by a few months but the physics runs should start, as foreseen, in early 2002. The planning of a specific observation program has been postponed until real data are available. It is hoped that one can still observe at first the CRAB nebula and use the data for calibrations. The AGN studies, as outlined in the physics targets of MAGIC, will very likely dominate in the first year of operation. End of 2002 the dedicated trigger for a low threshold observation of the CRAB will hopefully be ready in order to search for pulsed emission.

Multiwavelength observations will be an essential part of the observation program. Discussions are under way with AGILE for rapid information of flaring sources and with INTEGRAL for dedicated AGN observations. During most of the AGN observations, it is planned to have co-ordinated optical observations with the 60 cm KVA telescope operated by the Tuorla group on La Palma.

4 Ideas and perspectives for MAGIC phase II

Once the new technologies for MAGIC have proven to be successful we intend to prepare the phase II which will follow two directions: i) development of technology which was considered too risky or too expensive for phase I and ii) a multiple telescope observatory for either stereo observations or simultaneous multiple source observations.

4.1 Next steps in technology developments

Most of the activities concentrate on the development of photosensors with photocathodes of higher, red extended QE, as outlined in the design report. Inside the collaboration at least 4 activities are pursued along two directions . Very promising is a project with a leading PMT manufacturer who has already solved most of the production technology for an 18 mm diameter high QE, red extended photocathode. The other activity to improve the PMTs concentrates on replacing the classical dynodes by electron bombarded avalanche diodes.

Here we profit very much from the experience of one group developing avalanche photodiodes for HEP and nuclear medical applications. We are close to finalise the development contract for a hybrid PMT with an 18 mm diameter GaAsP photocathode of improved photon sensitivity and an APD with a combined gain of 7×10^4. The current MAGIC camera could at earliest be replaced by one of photosensors with about 3 times higher QE in about 2.5 years, provided the funds can be found.

Another technological development for phase II aims for an improved pulse time recording system. The current PMTs generate output pulses of 1.5 nsec width.

A recording system based on a $1 - 1.5$ Ghz FADC system should in principle allow one to improve on gamma/hadron separation and on further night sky background suppression.

Ghz FADCs are very expensive and power-hungry. The relatively low MAGIC trigger rate allows for large multiplexing, i.e. about 40 channels could be multiplexed on to one FADC. (see also report by Mirzoyan 2001) at this conference.

4.2 Multiple telescopes at the site

In parallel we are studying the augmentation of the installation in La Palma by more large IACTs, both for stereo observations, along the lines as outlined in the design report, and for multiple source observations. The currently allocated area in La Palma has room for 2 more large telescopes, which can be separated up to 120 m. There is plenty of room for the DAQ in the central counting house. As the trigger electronics is located also in the central counting house complex coincidence schemes can easily be implemented.

One of the planning difficulties for further expansions is the general experience that new ideas and the technology in this field are rapidly developing. The current mechanical telescope concept is easily expandable in size to even larger ones (25 m$-$30 m diameter) but the lower cost, work load and gain in time by simply copying MAGIC is non-negligible. No decision has been taken.

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