Technical Innovations for the MAGIC Project

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Abstract

Technical research and development for the MAGIC project started some eight years ago, with the clear goal to reach a high sensitivity for γ rays above 10-30 GeV. The data taking with the first MAGIC telescope will start in the next few months. We have developed and used for MAGIC several novel technologies, which were decisive for the successful completion of the worldwide largest air Cherenkov telescope. In the near future the MAGIC project will be upgraded by adding a second so-called ”clone” telescope. In this report we want to report on several more possible technical upgrades for the project in future.

1. Introduction

The progress in astronomy is driven by introduction of new technologies, methods and instrumentation. The MAGIC collaboration has introduced several novel technologies which allowed one to construct a large telescope with a very low energy threshold setting (Martinez, et al.,). Below are listed the main innovations used in MAGIC:

1. carbon-fibre tubular main frame of the reflector
2. all-Al diamond polished mirrors with internal heating
3. active mirror control of mirror elements
4. hemispherical bialkali PMTs with 6-dynodes (together with *Electron Tubes*)
5. light guides maximizing for photons double hit chance of PMT photocathode

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6. special coating of PMT windows for ~ 20 % increase in quantum efficiency
7. ultrafast analog signal transmission by using VCSEL diodes and fibres
8. 10 layer printed circuit mother-board in the camera for control and supply voltages and as a mechanical support
9. cooling of the camera by circulating water in a close loop thermostat
10. 2 level pattern trigger providing tight time coincidence (5 ns gate)

One shall mention that some of these technologies are taken over by other collaborations and implemented in their instruments (details of the items in the above list will be described elsewhere). The collaboration is continuing to work on several new technologies which might further improve the performance of imaging air Cherenkov telescopes. We are discussing below the new possibilities.

2. New technologies for the upgrade of the MAGIC project

Below are listed the novel technologies which could further improve the performance of the MAGIC project telescopes:

- Ultrafast FADC readout
- larger size, new design all *Al* mirrors
- concurrent mirror control by using infrared lasers and an infrared CCD
- piezoelectric actuators for the active mirror control
- very high reflectivity dielectric mirror foil for the light guides

2.1. Ultrafast FADC readout

For the best performance of a Cherenkov telescope one has to measure both the amplitude and the shape of Cherenkov pulses. These can be done by using ultrafast pulse shape digitizers. Cherenkov pulses have a duration of just of a few ns. In order to obtain the pulse shape one needs to sample $\geq 4-5$ points. This means one needs a FADC of a sampling rate of $\geq 2 GigaSamples/s$. Currently we are following two strategies:

1. Ultrafast FADC multiplexer based on optical fibre delay lines
2. Ultrafast analog sampler with capacitive memory and slow readout

The idea in option 1) is simple: because we are using analog signal transmission technique via optical fibres it is a small modification to split the incoming optical signal into two parts, one for the trigger and the other one for the shape measurements. The latter can be delayed in optical fibres without any noticeable shape degradation up to fibre lengths of $\sim 1km$ (or equivalent delay time of 5000 ns for the used VCSELs at $\lambda = 850nm$). By choosing the fibre length the analog signal from a given channel can be "qued" in a sequential chain until the analog switch of that channel will be turned on after the preset delay time letting the signal (after transforming light into an electrical signal) to pass through and to be measured by the FADC (Mirzoyan, et al.,). Currently we are designing a 16:1 FADC multiplexer.

In the option number 2) we are working on the development of a dedicated chip with CMOS technology to sample fast analog signals from the PMTs. The system is based on fast switching of capacitors used as temporary buffer elements. The capacitors are arranged in a ring fashion to sample continuously the analog input with a frequency $\geq 2GHz$. Upon the reception of an external trigger signal, the sampling wave is stopped, the collected charge is amplified and digitized by an external ADC. The ring buffer is made by 1024 capacitors thus providing a storage depth of $\sim 500ns$. This time window is deep enough to handle trigger signals coming from the experiment with up to 400 ns delay and providing a 100 ns window for the analog signal digitization.

2.2. Larger size new design mirrors

In MAGIC four mirror elements, each with a size of 49.5 x 49.5 cm^2, are fixed on a carrying panel of $\sim 1m^2$ size and are optically adjusted to perform better than a single piece $1m^2$ mirror. The reflector of MAGIC includes 245 panels of the above mentioned type. The panels are attached to electro-mechanical actuators to adjust their direction when varying the elevation angle. The weight of the mirror panels can be reduced and their design could be made simpler if one could construct a $\sim 1m^2$ single piece mirror elements. We are trying to produce $\sim 1m^2$ mirror blank elements of a spherical shape to be ready for the final polishing by using the diamond machined all Al mirror technology (Bastieri et al.,). Our ray tracing simulations show that if one will use the one piece $1m^2$ mirrors for MAGIC ($F/D = 1$), only the outer two rings of the mirrors shall be made from mirrors of 49.5 x 49.5 cm^2 size in order to to provide a point spread function of $\leq 0.1°$.

2.3. Infrared lasers and an infrared CCD for concurrent mirror control

In the current design of MAGIC we are using semiconductor laser pointers working at the wavelength of $\sim 650nm$ in the active mirror control (AMC) system. The lasers are fixed at the mirror panel center's and their light spots in the focal plane are adjusted to show the location of the reflected light spots of corresponding mirrors. When adjusting the mirror panels, because of bright laser light one has to stop for a short duration the data-taking. The infrared laser light is out of the sensitivity range of the conventional bialkali PMTs. Therefore the infrared lasers can be used in the AMC system for continuous mirror adjustment. The spots of the infrared lasers can be measured by using a CCD camera sensitive in the infrared part of the spectrum.

2.4. Piezoelectric actuators

In the MAGIC telescope we are using stepping motor based mechanical actuators under the control of micro-controllers for the optical adjustment of the mirror panels (Garczarczyk, et al.,). The vast majority of the panels need up-down movements with an amplitude of only $\sim 1mm$. We are considering to try to use piezoelectric actuators for the AMC. The latter can provide huge push or pull forces but only in a relatively short distance range of $\leq 0.5mm$. By using a lever arm it shall be possible to convert this short distance into a several times larger stroke and thus fulfill the AMC requirements for MAGIC.

2.5. Very high reflectivity dielectric foil for the light guides

We are planning to use a very high reflectivity ($\sim 98-99$ % for wavelengths above $\sim 330nm$) multi layer dielectric foil for lining the light guides in front of the PMTs in the camera.

3. Conclusions

The above mentioned new technologies can further improve the performance of the MAGIC project telescopes. While the ultrafast readout will allow us to lower the threshold energy of the telescope and to stronger reject backgrounds, the application of larger size mirrors, infrared lasers and the CCD, along with the possibility to use the piezoelectric actuators will improve the technical performance and the efficiency of the observations of the telescope.

4. References

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