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A G-APD based camera for Imaging Air Cherenkov Telescopes

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Imaging atmospheric Cherenkov telescopes (IACT) for Gamma-ray astronomy are presently using photomultiplier tubes as photo sensors. An interesting alternative are so-called Geiger-mode avalanche photodiodes (G-APD). They promise an improvement in sensitivity and, important for this application, in ease of construction (size and weight), operation (power consumption) and ruggedness. They have proven many of their features in the laboratory, but a qualified assessment of their performance in an IACT camera is best undertaken with a prototype.
The design and commissioning of a 36-pixel G-APD camera prototype is presented. Results obtained using a small zenith-looking Cherenkov telescope are shown. Sub-nanosecond time resolution has been achieved with the Domino Ring Sampling chip (DRS2) as primary data acquisition element. Using a majority-coincidence trigger, cosmic-ray induced air showers with clear time and intensity signatures have been recorded. Some of the points investigated with this setup are the control of the G-APDs large gain variation with temperature, and the behaviour under intense and changing night-sky background conditions.
The design of a full-scale 1440 pixel camera, planned to be installed on a 4 m diameter telescope by fall 2010 next to the MAGIC telescopes on La Palma, is also covered. After detailed studies on this novel technology, the camera will be used for routine and long-term monitoring of strong, variable gamma-ray sources (DWARF project).

Summary (Additional text describing your work. Can be pasted here or give an URL to a PDF document):

Imaging atmospheric Cherenkov telescopes (IACT) have been successful in detecting
high energy gamma-rays from cosmic sources in an energy range from 30 GeV to 30 TeV. Their key component is a pixelated, fast camera to resolve flashes of Cherenkov light from air showers (duration 1–5 ns for gamma-induced air showers, wavelength range 300–650 nm) within the background light of the night sky. High-sensitivity photo-sensors are mandatory since even a 1 TeV primary photon results in only about one hundred Cherenkov photons per square meter. Photomultiplier tubes are currently the detector of choice for this task.

Since a few years, a new type of semiconductor photo sensor is being developed, the so-called
Geiger-mode avalanche photodiode (G-APD). These devices, built from multiple APD cells operated in Geiger-mode, require bias voltages of only 50–100 V while reaching gains similar to photomultipliers. They can reach photon detection efficiencies of up to 50%, are rugged and not damaged by strong illumination like daylight.

For an IACT application under realistic ambient conditions, several technical challenges have to be met, however. This mainly concerns the necessity to compensate for gain variations due to changes in temperature or night-sky background light. Once achieved, a camera based on G-APDs can operate even under twilight and moonlight conditions, thus extending the accessible measurement time. The small size of the sensors further requires compact front-end electronics.

The construction of a small-scale camera prototype, the results from test measurements, and the design of a full-scale 5-degrees field-of-view camera are presented. In a second step, this device is foreseen for the DWARF telescope (Dedicated multi-Wavelength AGN Research Facility, to be located next to the MAGIC telescopes on La Palma, Canary Islands) which will perform monitoring of strong and varying gamma-ray sources.

The prototype comprises 144 Hamamatsu S10362-33-050C G-APDs, each with a sensitive area of 3x3 mm, covered by 3600 cells of 50x50 μm2 size, and a peak photon detection efficiency of 52%. Four G-APDs are summed to form one read-out channel. Non-imaging light collectors on top of each G-APD remove the effect of dead space between the sensors and provide a cross-section reduction by a factor 6.6. They are made of open aluminum cones with affixed reflecting foil.

A signal from a pulsed and temperature-stabilized light emitting diode is used in a feedback loop to stabilize the G-APD gain by regulating the bias voltage. In addition, a water cooling system stabilizes the temperature of the sensors. Because the dark count rate is negligible compared to the night-sky induced background, actual cooling is not necessary in this application. The camera is mounted inside a water-tight box with feed-throughs for signal and voltage cables. Analog signals are transferred over 20m long coaxial cables, and stored in analog pipelines operated at 2 GHz inside the DRS2 (Domino Ring Sampling) chips and finally digitized with a 40 MHz ADC. Majority triggering is achieved using standard VME electronics.

The high sampling frequency, together with corrections of the DRS2 fixed-pattern aperture jitter, result in a timing accuracy of 390 ps root-mean-square. This excellent accuracy is advantageous in the image cleaning step which is mandatory for interpreting data from a full-size Cherenkov telescope.

Clear intensity and time signatures from very high-energy (>10 TeV) proton showers were obtained in test measurements, using a 1 m diameter mirror in a zenith-looking configuration.

This setup, both in camera resolution and mirror area, is too small to allow a clear discrimination of gamma-ray initiated showers from the much more abundant proton showers. To fully validate this technology for IACTs, a larger camera with 1440 pixels, based on the same type of sensor and on the next-generation DRS4 analog pipeline chip, is currently constructed. As major step, all signal digitization and trigger generation will be located inside the camera, transferring only digital data via Ethernet from the camera, and low- and bias voltages to the camera.

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