PROCEEDINGS OF SCIENCE

The INFN contribution to the study of a Cherenkov camera demonstrator for CTA

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In October 2013, the Italian Ministry approved the funding of a Research & Development (R&D) study, within the "Progetto Premiale TElescopi CHErenkov made in Italy (TECHE)", submitted by the Istituto Nazionale di Astrofisica (INAF) and the Istituto Nazionale di Fisica Nucleare (INFN), and devoted to the development of a demonstrator for a camera for the Cherenkov Telescope Array (CTA) consortium. Here, we present the organization of the "Progetto Premiale", the working packages contents and the expected objectives.

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1. The Progetto Premiale TECHE.it

CTA (Cherenkov Telescope Array) is a world-wide project devoted to ground-based gamma-ray astronomy, counting on the participation of the majority of EU countries [1, 2]. Indeed EU is supporting CTA Preparatory Phase within the FP7 program. During such Preparatory Phase, INAF and INFN obtained ad hoc funds from the Italian Ministry of Education, Universities and Research (MIUR) in the framework of the flagship projects for a total of 8M€ for the time interval 2010–13.

The CTA experiment will include two arrays of about 100 telescopes in total which will detect gamma-rays in from few tens of GeV to more than 100 TeV. It will improve by at least one order of magnitude the sensitivity of the Very High Energy (VHE) telescopes currently in operation (like H.E.S.S. [3, 4], MAGIC [5, 6] and VERITAS [7]) and will be a facility open to the whole astrophysical community. Indeed, among future projects, CTA was ranked at the highest priority in Europe and USA (Aspera, Astronet, ESFRI, US Decadal Review). The success of such a complex project rests on challenging scientific and technical developments, four of which could benefit from Italian know-how and innovative approach: (1) the industrial production of low-cost telescopes ideally suited to detect Cherenkov emission of relativistic particles produced by celestial gamma-rays; (2) the development and production of silicon-based photon detectors; (3) the development of novel front-end electronics to digitize, read and transfer the detector signals; and (4) the extremely rapid analysis pipeline based on the use of Graphical Processing Units (GPUs), in order to make it possible to perform real time analysis. INAF and INFN, in collaboration with several Italian industries, are developing innovative technologies in these four fields.

2. Working Packages

The structure of the Teche.it project is shown in Fig. 1. It is subdivided in 4 working packages (*WP*), where *WP1* and *WP4* are lead by INAF while *WP2* and *WP3* by INFN. *WP1*, in collaboration with French institutes, aims at developing low-cost telescopes to be built in a cost effective way by industrial partners, such as BCV Progetti and Tomelleri srl. *WP2*, together with the Italian industry Fondazione Bruno Kessler (FBK in Trento[1]), aims at developing a demonstrator to bring Italy in the forefront of the silicon detector worldwide market. *WP3* aims at developing a fast electronics customized for the detector, transferring the INFN know-how into the astrophysical arena. CAEN in Viareggio[2] and SITAEL in Bari[3] are the industrial partners. *WP4* is devoted to the development of a fast pipeline to combine the signals produced by the telescope array at the observing site. This will be done using state-of-the-art GPUs and exploiting the know-how acquired by INFN and INAF as well as other industrial partners such as NVIDIA and Eurotech.

3. Objective

VHE gamma-ray astronomy (GeV–TeV) is one of the most recent branches of relativistic astrophysics. Gamma rays are a form of electromagnetic radiation much more energetic than visible

[1]see http://www.fbk.eu/
[2]see http://www.caen.it/
[3]see http://www.sitael.com/

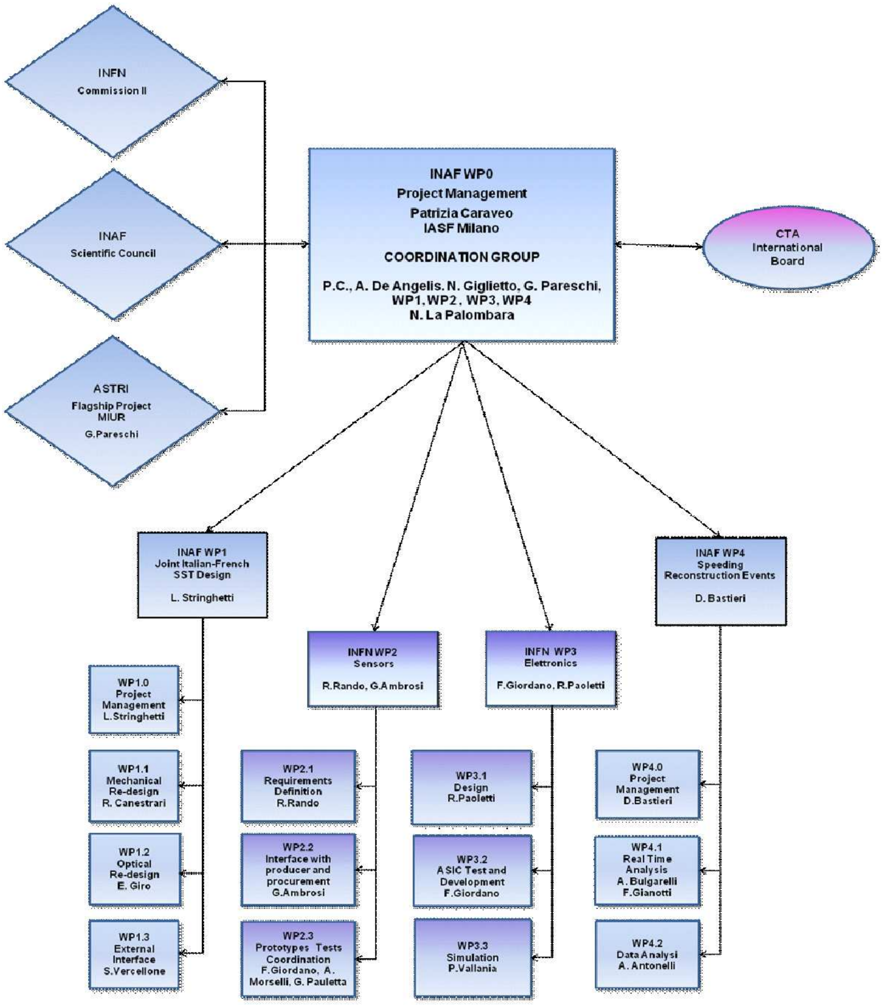

Figure 1: PBS of the Teche.it project

light and they are absorbed by the Earth's atmosphere. Since the beginning of the space age, gamma rays have been studied by space missions which, however, cannot go beyond 100 GeV owing to extremely low flux value. This is why very high-energy gamma-ray astronomy is done from the ground. In fact, when entering the atmosphere, gamma-ray photons interact with atmospheric nuclei and produce a shower of highly-energetic secondary particles which move with a speed greater than that of light in air [8, 9]. In 1934, the physicist Pavel Cherenkov noted that this phenomenon produced bluish luminescence, conceptually similar to the sonic boom in air. It is a very short lived emission (few billionths of a second) and a very faint one, which can be detected using telescopes sensitive to low light fluxes at ground level and equipped with extraordinarily fast and efficient focal cameras. As a matter of fact, the current generation of ground based gamma-ray telescopes has started to produce important results only when it was understood that global instrument performance increased very significantly several telescopes working in stereoscopic mode. To give some examples: the H.E.S.S. experiment consists of five telescopes (four 12 m telescopes placed around one central 28 m telescope), operating in Namibia. The VERITAS experiment is formed by four 12 m telescopes and operates in Arizona (USA). The MAGIC experiment operates two 17 m telescopes on the La Palma Canary Island (Italy is strongly involved in the MAGIC collaboration). These instruments have so far populated the ultrahigh-energy gamma-ray sky with over a 150 sources, finally showing that the Universe is rich in celestial objects capable of producing extremely energetic radiation. The CTA collaboration already involves more than 1000 scientists from all over the world, who will bring together their efforts in order to understand the behavior of these powerful celestial accelerators. Owing to a tenfold increase in the number of detected sources, CTA will change our perception of the gamma-ray sky, unveiling hundreds of sources in our galaxy, such as black holes, supernova remnants, star forming regions, pulsars, and binary systems, as well as possible extragalactic sources.

In order to be able to assess the entire sky, the CTA project foresees two observing facilities, one in the Northern, and one in the Southern hemisphere. Each observatory will host different kind of telescopes. At the center, few large (around 23 m diameter) telescopes are foreseen, with many medium sized telescopes (around 12 m diameter) surrounding them. In addition, many small telescopes (around 4 m diameter) will be spread over a large area in the Southern Hemisphere array. The three types of telescope are designed to sample the light produced by gamma rays with different energies.

4. The mechanics

Within the CTA project, INAF decided to focus its efforts on the development of the Small Size Telescopes (SST) which will cover the region between few TeV and until more than 100 TeV, thus having the highest potential for revolutionary discoveries. In developing its SST, INAF took an innovative approach based on a dual mirror Schwarzshild-Couder design, deemed more promising than the usual single mirror one. Such an approach has been pursued thanks to the ASTRI MIUR flagship project as well as to a PRIN project in common with INFN and a number of Universities. An end-to-end SST prototype is being built at the observing site of the Catania INAF observatory on the Etna mountain. The ASTRI flagship project is meant to demonstrate the capability to handle all the subsystems needed by a successful SST, ranging from the mechanics and the focal plane detector, up to the read-out electronics and the data analysis. Only by achieving a leadership position in all of these areas, the Italian proposal can be competitive in the International community.

The Italian effort is appreciated by the CTA collaboration, though Italy is not the only nation involved in the construction of an SST prototype. In parallel to ASTRI, French colleagues from the Observatoire de Paris are developing GATE, a dual mirror SST based on a different mechanical and optical design. While the development of two different prototypes is beneficial at the beginning of a project, the final array of SSTs might be based on a unique design, including elements from both proposals. This will allow to optimize the construction costs, as well as the on-site maintenance. Thus, INAF and Observatoire de Paris has signed an agreement [10] to develop a common project once the comprehensive testing of ASTRI and GATE will be finished. This decision implies an additional effort (not foreseen within the ASTRI flagship project) to revisit the original ASTRI mechanical and optical design to produce a new design encompassing the best features of the French and Italian original projects. Next, using such novel design, one (or two) prototypes should

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be built to allow a thorough verification campaign. Such step is essential if the joint design is to become the baseline for 70 replica SSTs in the Southern observing facilities of CTA.

5. The Camera

5.1 Silicon Photo-multipliers

Silicon Photo-multipliers (SiPMs) can be the building blocks of the detectors for a new generation of focal cameras in Imaging Air Cherenkov Telescopes (IACT). When engineered, they will increase the overall light detection efficiency and improve the spatial and angular resolution of the telescopes. Already existing prototype devices achieve better light detection efficiency than standard photomultiplier tubes (PMTs). In addition, the size of the detector elements (a few square millimeters) is appropriate for small telescopes (SST). Among the advantages that a SiPM shows compared to conventional phototubes, there is the ability to recover the full functionality in less than 100 ns after exposure to very intense light. Therefore, the use of SiPMs could increase the duty cycle of IACT arrays, allowing observations in moon conditions, and gaining approximately 30%-40% compared to the current PMT-based cameras of MAGIC and H.E.S.S. The price of each pixel is already lower than that of a standard PMT and is expected to further decrease as mass production of these devices start in standard CMOS foundries. Furthermore, improvement of the Photon Detection Efficiency (PDE) of SiPMs is expected to be achieved by industries in the near future as a result of joint R&D programs between research institutes and the manufacturers. However, SiPMs still present a high level of dark current, afterpulsing and crosstalk. Current R&D programs in detector development are addressing these issues. The Japanese company Hamamatsu, is already developing prototypes. We want to go along the same direction, too, developing a research line on photosensors together with FBK.

5.2 Front-end electronics

The front-end electronics has a key role for the success of demonstrating the feasibility of the SiPM camera design. The camera electronics must be compact and with a high density of channels. This implies mechanical simplicity and the possibility of having "in-house" as much data processing as possible. Compactness also is the key to minimize the noise, reaching the sensors with minimum cabling. The solution adopted relies on early signal digitization using ASIC. The specific electronic must be developed. In this respect, INFN has a long standing synergy with leader industries (like CAEN) which have been the backbone for LHC experiments, and SITAEL, which has a great expertise in electronics for space applications.

6. The Demonstrator

INFN groups involved in the "Progetto Premiale TECHE.it" are now involved together with the industrial partners in the construction of a demonstrator. It will consits of a SiPM plane of 16 channel 6 mm $\times$ 6 mm obtained by summing up four 3 mm $\times$ 3 mm like the one presented in [11]. The signals from the silicon plane will be conditioned by a PCB housing the electronics, which will be coupled through a rigid flex to a board dedicated to the trigger formation and digitization

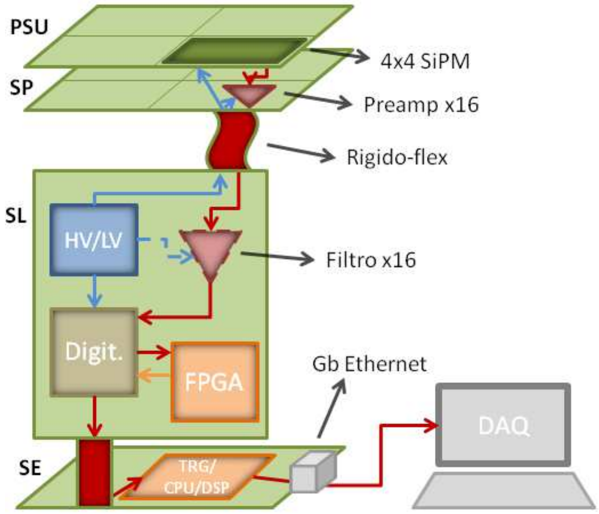

Figure 2: Sketch of the demonstrator

of the voltage signals from the preamplifiers. A sketch of the demonstrator design is shown in Fig. 2. In addition, a cluster of 7 1" SiPM obtained by 3x3 or 6x6 elements, similar to what needed for the geometry of the Large Size Telescope, will be produced and tested on the MAGIC telescope.

7. Acknoledgments

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